Prices, governance challenges and contracts in scaling of biofortification

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Alioma Richard

From Maracha, Uganda

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Head of the examination committee: Prof. Dr. Andrea Knierim

Supervisor and Reviewer: Prof. Dr. Manfred Zeller

Co-reviewer: Prof. Dr. Steffen Abele

Additional examiner: Prof. Dr. Georg Cadisch

Dedication

To Kobeson, Polina, Nelson, Emmanuela, Emmanuel, Cynthia, Franklyn, and Sophie

Table of contents

List of tables

List of figures

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Executive summary

Micronutrient deficiency remains a global health challenge, especially in developing countries, despite government and development partners' programs, numerous policies, and interventions to decrease its prevalence. Micronutrient deficiency adversely affects pregnancy, child growth, disease susceptibility, and cognitive development. Populations suffer from deficiencies due to low intake of micronutrients such as iron, zinc, vitamin A and iodine in their diets. Therefore, many interventions and policies have aimed at increasing the intake of micronutrients by the target populations. Some of these interventions include fortification, that is to increase the micronutrient content of foods or condiments, biofortification which entails breeding staple crops with higher content of bioavailable micronutrients, supplementation, and dietary diversity.

These interventions face numerous challenges to scale to larger populations mainly because of behavioural attributes, prices, and governance challenges. The importance of prices stretches from academia to policymakers because of its substantial impact on the consumption behaviour of poor households affecting micronutrient intake. Existing literature on prices concentrated on the cost of micronutrient-dense foods compared to starchy staple foods and the price change for different food items. The second challenge in the scaling of interventions is governance challenges. Governance challenges exist in formal and informal institutions affecting the value chain for biofortified seeds or foods. These challenges jeopardize positive development outcomes and may as well pose significant obstacles to scaling the use of biofortified seed and food. Lastly, there has been a growing focus on the involvement of aggregators, processors, and retailers in the development of food value chains in low-income countries, yet the role of supply contracts is unknown. The objectives of this thesis are threefold: 1) to estimate the long-term trends in prices and volatility of micronutrient-dense food as opposed to starchy staple food and derive hypotheses for factors that might have contributed to the observed divergence in the past long-term growth of prices of micronutrient-dense versus starchy food 2) to identify the governance challenges facing farmers, seed multipliers, aggregators, processors, and retailers as one of the scaling pathways and empirically test one pathway to address the governance challenge in Uganda and 3) to determine the distribution and performance of aggregators, retailers, and processors in Nigeria's vitamin A food value chain.

This cumulative thesis has three papers. The first paper seeks to answer as main question: “Do prices of micronutrient-dense food commodities grow faster than prices of starchy staple food

items". The second paper poses the following as its main question: "What are the governance challenges in scaling biofortified crops". The third paper addresses the question of which factors determine the distribution and performance of aggregators, processors, and retailers in the development of value chains for staple food crops.

In the first paper, we used the autoregressive and panel autoregressive distributed lag models to analyze the trends in relative prices and the effects of income growth. The data set was price data for micronutrient and calorie-dense foods from FAO STAT-GIEWS, IMF, and the World Bank. The results showed that micronutrient-dense food prices in real terms grew on average by 0.03% per month more than starchy staple food prices, with the expectation of a 12% growth gap in the next 30 years. The volatility of micronutrient-dense food items exceeds starchy staple foods in most domestic markets. Also, the prices of micronutrient-dense foods were more volatile in international markets than in most developing countries. Income growth in developing countries is hypothesized to be one of the factors that contributed to the faster growth in demand for and, therefore, prices of micronutrient-dense food commodities. Other factors, such as the growth in the production of staple foods may have caused price trends to persist.

After having presented evidence that prices of micronutrient-dense foods have grown faster in the past 30 years, and if this trend continues, interventions for scaling biofortification, among others, will gain importance for eradicating hidden hunger. In the second paper, we provide insights into the governance challenges of biofortification in Uganda. This paper aims to identify the governance challenges facing farmers, seed multipliers, aggregators, processors, and retailers as one of the scaling pathways and empirically test one pathway to address the governance challenge. This pathway was information provision through training. We used a Process Net-Map to elicit information from respondents regarding processes, actors, and challenges in the food value chain of biofortified crops. The Process Net-Map involves the identification of actors, their roles, their influence on the scaling of biofortification and challenges in the processes. The field lab experiment was used to collect data on the effect of information provision on the identification of iron beans. We analysed the data from field lab experiments through a correlated random effects model. The results demonstrate that vine multipliers face challenges in the supply of vines, and households face a trade-off between allocating land for orange-fleshed potatoes and other varieties. In addition, the value chain actors adulterate iron beans while consumers are unwilling to pay a premium for orange-fleshed sweet potato roots and iron bean grains. These challenges may result from information asymmetry, merit goods, collective action, and free riding. Though information provision can improve the identification of iron beans, its effect was insignificant as from the field lab experiments. Increasing access to biofortified seed through subsidies would increase the production of biofortified crops that would saturate the markets. Creating awareness of the importance of nutritious products would enable consumers to pay for biofortified seeds and food.

The third paper provides evidence on factors determining the distribution and performance of aggregators, retailers, and processors in Nigeria's vitamin A food value chain. We used data collected by HarvestPlus to assess the outcome indicators, including throughput, sales, prices, variable costs and contracts for vitamin A cassava and maize. We used the spatial distributed lag model to determine factors that affect the distribution of aggregators, retailers and processors and the correlated random effects model to assess the role of contracts on their performance. We find that infrastructural and supply variables do not influence the location of aggregators, retailers, and processors. Out of the demand variables (population density, ownership of livestock and literacy rates, price of *Garri*-cassava flour), only the price of *Garri* and livestock ownership influenced the location of aggregators, retailers, and processors. Contracts seem to reduce the cost per kilogram for aggregators while insufficiently affecting the costs of retailers and processors. Contracts are also associated with improving the profits of retailers and aggregators.

The main policy recommendations emanating from the findings of this thesis are: 1) governments need to adopt policies that enhance nutrition-sensitive interventions such as supplementation, fortification, dietary diversity, and biofortification 2) employ subsidies to increase the production of biofortified crops while creating awareness on the importance of nutritious products in the scaling of biofortified crops and 3) create enabling environments so that aggregators, retailers and processors can engage in contracts with farmers.

Zusammenfassung

Mikronährstoffmangel stellt nach wie vor ein globales Gesundheitsproblem dar, vor allem in Entwicklungsländern, trotz zahlreicher Maßnahmen, Interventionen und Programmen von Regierungen und Entwicklungsorganisationen zur Reduzierung der Verbreitung. Mikronährstoffmangel wirkt sich negativ auf die Schwangerschaft, das Wachstum des Kindes, die Anfälligkeit für Krankheiten und die kognitive Entwicklung aus. Eine Bevölkerung leidet unter Mikronährstoffmangel, weil sie zu wenig Eisen, Zink, Vitamin A und Jod mit der Nahrung aufnimmt und die Mikronährstoffe aus den Darmwänden entweichen. Daher zielen viele Interventionen und Maßnahmen darauf ab, die Aufnahme von Mikronährstoffen zu erhöhen. Einige dieser Maßnahmen umfassen 1) die Anreicherung; die Erhöhung des Mikronährstoffgehalts von Lebensmitteln oder Zutaten, 2) die Biofortifikation, die Züchtung von Grundnahrungsmitteln mit höherem Mikronährstoffgehalt, und 3) die Supplementierung, die Einnahme von Kapseln oder Nahrungsmitteln, die die Vielfalt der Mikronährstoffe und der Ernährung erhöhen sollen.

Diese Maßnahmen stehen vor zahlreichen Herausforderungen bei der Ausweitung auf größere Bevölkerungsgruppen, vor allem aufgrund von Verhaltensmerkmalen, Preisen und Governance-Problemen. Die Bedeutung der Preise reicht von der Wissenschaft bis hin zu politischen Entscheidungsträgern, da sie das Konsumverhalten armer Haushalte und damit die Aufnahme von Mikronährstoffen erheblich beeinflussen. Die vorhandene Literatur über Preise konzentriert sich auf die Kosten von Nahrungsmitteln mit hohem Mikronährstoffgehalt im Vergleich zu stärkehaltigen Grundnahrungsmitteln und auf die Preisveränderungen bei verschiedenen Nahrungsmitteln. Die zweite Herausforderung bei der Skalierung von Interventionen sind Governance-Probleme. Diese bestehen bei formellen und informellen Institutionen, die zur Wertschöpfungskette für biofortifiziertes Saatgut oder Nahrungsmittel beitragen. Diese Herausforderungen gefährden positive Entwicklungsergebnisse und können auch erhebliche Hindernisse für die Ausweitung der Verwendung von biofortifiziertem Saatgut und Nahrungsmitteln darstellen. Schließlich wurde die Beteiligung von Aggregatoren, Verarbeitern und Einzelhändlern an der Entwicklung von Nahrungsmittelwertschöpfungsketten in Ländern mit niedrigem Einkommen immer stärker in den Mittelpunkt gerückt, doch die Rolle von Lieferverträgen ist unbekannt.

Vor diesem Hintergrund sind die Ziele dieser Arbeit dreifach: 1) Abschätzung der langfristigen Trends bei Preisen und Preisvolatilität von mikronährstoffreichen Nahrungsmitteln im Vergleich zu stärkehaltigen Grundnahrungsmitteln und Ableitung von Hypothesen zu Faktoren,

die zu der beobachteten Divergenz in der langfristigen Preisentwicklung von mikronährstoffreichen und stärkehaltigen Nahrungsmitteln in der Vergangenheit beigetragen haben könnten. 2) Identifizierung der Governance-Probleme, mit denen Landwirte, Saatgutmultiplikatoren, Aggregatoren, Verarbeitern und Einzelhändlern konfrontiert sind, und Skalierungspfade empirisch zu testen, um die Governance-Herausforderung zu adressieren in Uganda, und 3) die Verteilung und Leistung von Aggregatoren, Einzelhändlern und Verarbeitern in Nigerias Vitamin-A-Nahrungsmittel-Wertschöpfungskette zu bestimmen.

Diese kumulative Arbeit besteht aus drei wissenschaftlichen Artikeln. Der erste Artikel versucht die Frage zu beantworten, ob die Preise für mikronährstoffreiche Nahrungsmittel schneller als die Preise für stärkehaltige Grundnahrungsmittel steigen. Der zweite Artikel wirft die Frage auf, was die Herausforderungen für die Governance bei der Vermarktung biofortifizierter Nutzpflanzen sind. Der dritte Beitrag befasst sich mit der Frage, welche Faktoren die Verteilung und Leistung von Aggregatoren, Verarbeitern und Einzelhändlern bei der Entwicklung von Wertschöpfungsketten für Grundnahrungsmittel bestimmen.

Im ersten Beitrag verwenden wir autoregressive und Panelmodelle mit autoregressiver verteilter Verzögerung, um die Entwicklung der relativen Preise und die Auswirkungen des Einkommenswachstums zu analysieren. Als Datensatz dienen Preisdaten für mikronährstoff- und kaloriendichte Nahrungsmittel von FAO STAT-GIEWS, dem Internationalen Währungsfonds und der Weltbank. Die Ergebnisse zeigen, dass die realen Preise für mikronährstoffreiche Nahrungsmittel im Durchschnitt um 0,03 % pro Monat stärker stiegen als die Preise für stärkehaltige Grundnahrungsmittel, wobei in den nächsten 30 Jahren ein Wachstumsgefälle von 12 % zu erwarten ist. Die Preisvolatilität von mikronährstoffreichen Nahrungsmitteln übersteigt die von stärkehaltigen Grundnahrungsmitteln auf den meisten Binnenmärkten. Auch waren die Preise für mikronährstoffreiche Lebensmittel auf den internationalen Märkten volatiler als in den meisten Entwicklungsländern. Es wird angenommen, dass das Einkommenswachstum in den Entwicklungsländern einer der Faktoren ist, die zum schnelleren Anstieg der Nachfrage nach mikronährstoffreichen Nahrungsmitteln und damit auch der Preise beigetragen haben. Andere Faktoren, wie die Zunahme der Produktion von Grundnahrungsmitteln, könnten dazu geführt haben, dass der Preistrend anhält.

Nachdem wir den Nachweis erbracht haben, dass die Preise für mikronährstoffreiche Lebensmittel in den letzten 30 Jahren schneller gestiegen sind, und für den Fall, dass sich dieser Trend fortsetzt, werden unter anderem Maßnahmen zur Ausweitung der Biofortifikation für die

Beseitigung von verstecktem Hunger an Bedeutung gewinnen. Im zweiten Beitrag geben wir einen Einblick in die Governance-Herausforderungen der Biofortifikation in Uganda. Dieser Artikel zielt darauf ab, die Governance-Herausforderungen für Landwirte, Saatgutvermehrer, Aggregatoren, Verarbeiter und Einzelhändler als einen der Skalierungspfade zu identifizieren und einen Pfad zur Bewältigung der Governance-Herausforderungen empirisch zu testen. Dieser Pfad war die Bereitstellung von Informationen durch Trainings. Wir verwenden die "Process Net-Map-Methode, um von den Befragten Informationen über Prozesse, Akteure und Herausforderungen in der Wertschöpfungskette biofortifizierter Nutzpflanzen zu erhalten. Die Process Net-Maps beinhalten die Identifizierung von Akteuren, deren Rollen, deren Einfluss auf die Skalierung der Biofortifikation und Herausforderungen in den Prozessen. Ein Feld-Experiment wurde genutzt, um Daten über die Auswirkungen der Informationsbereitstellung auf die Identifizierung von Eisen-biofortizifierten Bohnen zu sammeln. Wir analysierten die Daten aus den Experimenten mithilfe eines Regressionsmodells mit korrelierten Zufallseffekten. Die Ergebnisse zeigen, dass die Multiplikatoren von Süßkartoffelstecklingen mit Problemen bei der Versorgung mit Stecklingen konfrontiert sind und die Haushalte einen Kompromiss zwischen der Zuteilung von Land für biofortizifierte orangefarbene Süßkartoffeln und anderen Sorten eingehen müssen. Darüber hinaus verfälschen die Akteure der Wertschöpfungskette Eisen-biofortizifierten Bohnen, während die Verbraucher:innen nicht bereit sind, einen Aufpreis für biofortifizierte Bohnen zu zahlen. Diese Herausforderungen können auf Informationsasymmetrie, meritorische Güter, kollektives Handeln und Trittbrettfahren zurückzuführen sein. Obwohl die Bereitstellung von Informationen die Identifizierung von Eisen-biofortizifierten Bohnenverbessern kann, war ihr Effekt unbedeutend, wie die Feldexperimente zeigten. Ein verbesserter Zugang zu biofortifiziertem Saatgut durch Subventionen würde den Anbau biofortifizierter Nahrungsmittel erhöhen, was zu einer Sättigung der Märkte führen würde. Die Schaffung eines Bewusstseins für die Bedeutung nährstoffreicher Produkte würde Zahlungsbereitschaft von Verbraucher:innen erhöhen.

Der dritte Beitrag liefert Erkenntnisse über die Faktoren, die die Verteilung und Leistung von Aggregatoren, Einzelhändlern und Verarbeitern in der nigerianischen Vitamin-A-Nahrungsmittelwertschöpfungskette bestimmen. Wir verwenden jährliche Daten, die von HarvestPlus erhoben werden, um die Ergebnisindikatoren zu bewerten, einschließlich Durchsatz, Verkäufe, Preise, variable Kosten und Verträge für Vitamin-A-Maniok und -Mais. Wir verwenden ein Spatial-Distributed-Lag-Modell, um die Faktoren zu bestimmen, die sich auf die Verteilung von Aggregatoren, Einzelhändlern und Verarbeitern auswirken, und ein Modell mit korrelierten Zufallseffekten, um die Rolle von Verträgen auf ihre Leistung zu bewerten. Wir stellen fest, dass Infrastruktur- und Angebotsvariablen keinen Einfluss auf den Standort von Aggregatoren, Einzelhändlern und Verarbeitern haben. Von den Nachfragevariablen (Bevölkerungsdichte, Viehbesitz und Alphabetisierungsrate, Preis für Maniokmehl) beeinflussten nur der Preis für Maniokmehl und der Viehbesitz den Standort von Aggregatoren, Einzelhändlern und Verarbeitern. Verträge scheinen die Kosten pro Kilogramm für die Aggregatoren zu senken, während sie die Kosten der Einzelhändler und Verarbeiter nur unzureichend beeinflussen. Verträge werden auch mit einer Verbesserung der Gewinne von Einzelhändlern und Aggregatoren in Verbindung gebracht.

Die wichtigsten politischen Empfehlungen, die sich aus den Ergebnissen dieser Arbeit ergeben, sind: Die Regierungen müssen 1) Maßnahmen ergreifen, die Nahrungsergänzung, Anreicherung, Ernährungsvielfalt und ernährungssensible Interventionen wie die Biofortifikation fördern, 2) Subventionen einsetzen, um den Anbau biofortifizierter Nahrungsmittel zu steigern, und gleichzeitig ein Bewusstsein für die Bedeutung nahrhafter Produkte bei der Ausweitung biofortifizierter Nahrungsmittel schaffen, und 3) ein günstiges Umfeld schaffen, damit Aggregatoren, Einzelhändler und Verarbeiter Verträge mit Landwirten abschließen können.

List of acronyms

ARDL	Autoregressive Distributed Lag
CGAIR	Consultative Group for International Agricultural Research
CIP	International Potato Centre
DFE	Dynamic Fixed Estimator
DVM	Decentralized Vine Multipliers
FAO-GIEWS	Global Information and Early Warning System on Food and Agriculture.
GAIN	Global Alliance for Improved Nutrition
GARCH	Generalized Autoregressive Conditional Heteroskedasticity
GDP	Gross Domestic Product
GIS	Geographical Information Systems
IMF	International Monetary Fund
LGAs	Local Government Areas
LISA	Local Indicators of Spatial Association
LSMS	Living Standards Measurement Study
NARO	National Agricultural Research Organization
NDP	National Development Plan
OFSP	Orange Fleshed Sweet Potatoes
PMG	Pooled Mean Group
SACCO	Saving and Loans Cooperative Organizations
SDGs	Sustainable Development Goals
VCAs	Value Chain Actors
WHO	World Health Organization

Chapter one

1.0 Introduction

Micronutrient deficiency is one of the main contributors to the global burden of disease (Vos et al. 2020), affecting over 2 billion people worldwide (FAO, 2013). The prevalence of micronutrient deficiency varies by region, sex, and age. Han et al. (2022) noted that Central and Eastern Sub-Saharan Africa have the highest zinc deficiency, South Asia is most affected by vitamin A deficiency, and Western Sub-Saharan Africa has the highest iron deficiency. Women and children suffer most from both iron and vitamin A deficiency whose effects are adverse and long-lastingThese effects include pregnancy complications, child growth retardation, increased disease susceptibility, and impaired cognitive development (Biesalski et al., 2011). Studies have documented both the economic and health costs of micronutrient deficiency. Stein and Qaim (2007) estimated the economic cost of micronutrient deficiency to India to range between 0.8% to 2.5% of its gross domestic product (GDP). Akseer et al. (2022) found that childhood stunting costs the private sector at least US$135.4 billion in sales annually in low and middle-income countries, translating into 0.01% to 1.2% of national GDP across countries.

Several factors have determined micronutrient deficiency rates (Bai et al., 2021; Madjdian et al., 2018; Haddad, 2000). One of the main factors is the affected populations' inadequate micronutrient intake. The low intake of micronutrients may be due to socioeconomic, cultural, and institutional factors. These factors include income, religion, ethnicity, educational and literacy level, working status, and marital status (Madjdian et al., 2018). Apart from individual-level factors, micronutrient deficiency is associated with community-level factors like residence, sanitation, school type, and seasonality (Madjdian et al., 2018). Food commodity price increases may also affect micronutrient deficiency rates by reducing dietary diversity (Bouis et al., 2011; Bouis and Hunt, 1999; Bouis et al., 1990). Amolegbe et al. (2021) showed that increasing rice prices reduces dietary diversity and food share of consumption expenditure.

National and global policymakers have developed policies to reduce micronutrient deficiency that translate into development goals. For example, the Sustainable Development Goals (SDGs) target is to “end all forms of malnutrition by 2030” (UNICEF, 2016). Globally this goal can be achieved by reducing child stunting by 40% and anaemia among women of reproductive age by 50% (WHO, 2017). Different organizations and governments have other targets to contribute to the overall global target. For example, the Consultative Group for

International Agricultural Research (CGIAR) aimed at having 150 million people move out of micronutrient deficiency by 2030 in developing countries (CGIAR, 2015).

Governments and development partners have used several interventions to reduce the prevalence of micronutrient deficiency. The most common strategies include supplementation, fortification, dietary diversity and biofortification. Supplementation is using iron pills or vitamin A capsules to increase the intake of these minerals and vitamins (Das et al., 2013; Imdad et al., 2011). Imdad et al. (2011) showed that Vitamin A supplementation led to a 25% reduction in all-cause mortality in children between 6 to 59 months. The success of supplementation depends on the existing medical infrastructure and education (Bailey et al., 2015). In other words, the coverage of either vitamin A or iron supplementation may be low in remote rural areas with poor health infrastructure and low levels of education. Moreover, although unquestionably beneficial, supplementation programs do not address the underlying issue of a poor-quality diet linked to a small variety of foods or a diet centred on staple crops with a low level of micronutrients.

Fortification is another strategy to reduce micronutrient deficiency that involves industrially adding minerals into foods. Many food commodities have been fortified with minerals and vitamin A. These include iodised salt; cooking oil, sugar, flour, dairy foods, and condiments (Bouis et al., 2017). Despite progress in the fortification, uptake relies on income, behaviour change and policy. Other challenges that may impede the scaling of fortified foods include cost and adequate distribution (De-Regil et al., 2013).

Biofortification is an emerging approach to reducing micronutrient deficiency central to this thesis. It is the development of crops that accumulate higher amounts of a particular micronutrient by harvest than standard crops (Saltzman et al., 2017; Birol et al., 2015). Biofortification of staple crops can help improve a poor-quality diet, especially where food choices are limited. The progress in biofortification can be seen in breeding, consumption of biofortified crops and policy. More than 400 biofortified crop varieties have been released and over 20 million people worldwide are currently estimated to be consuming biofortified crops (Bouis and Saltzman, 2017).

1.1 Scaling of biofortification

Despite the success in breeding staple food crops with a higher bioavailable micronutrient content, scaling of biofortification is essential to make any meaningful impact on hidden hunger. Scaling of biofortification seeks to have many people produce and consume biofortified crops. For example, the scale-up analysis of Orange Fleshed Sweet Potatoes (OFSP) suggests strategies to increase the number of people producing and consuming OFSP (Mulongo et al., 2021). Foley et al. (2022) noted that scaling would mean over 1 billion people consuming biofortified food crops by 2030. Therefore, the scaling would involve a process that encourages breeding, seed multiplication, production, distribution, and consumption, as shown in figure 1.1.

Mainstreaming the breeding of biofortified crops into national research programs and the production of seed by the private sector is essential for scaling. Mainstreaming ensures the continuous release of biofortified crop varieties and the production of seeds. The mainstreaming into breeding research involved investment in the capacity building of scientists and equipment (Foley et al., 2021; Mulongo et al., 2021). The seed system's approach to scale depended on the country and crop. For example, in India and Zambia, the released biofortified crop varieties were licenced to seed companies to produce certified seeds (Foley et al., 2021). The OFSP projects in sub–Saharan Africa established a seed system based on a three-tier system. The first tier is where the clean planting material is obtained, usually from research stations. The second tier is primary multipliers called decentralized vine multipliers (DVM), and the third tier is the tertiary multipliers (Mulongo et al., 2021).

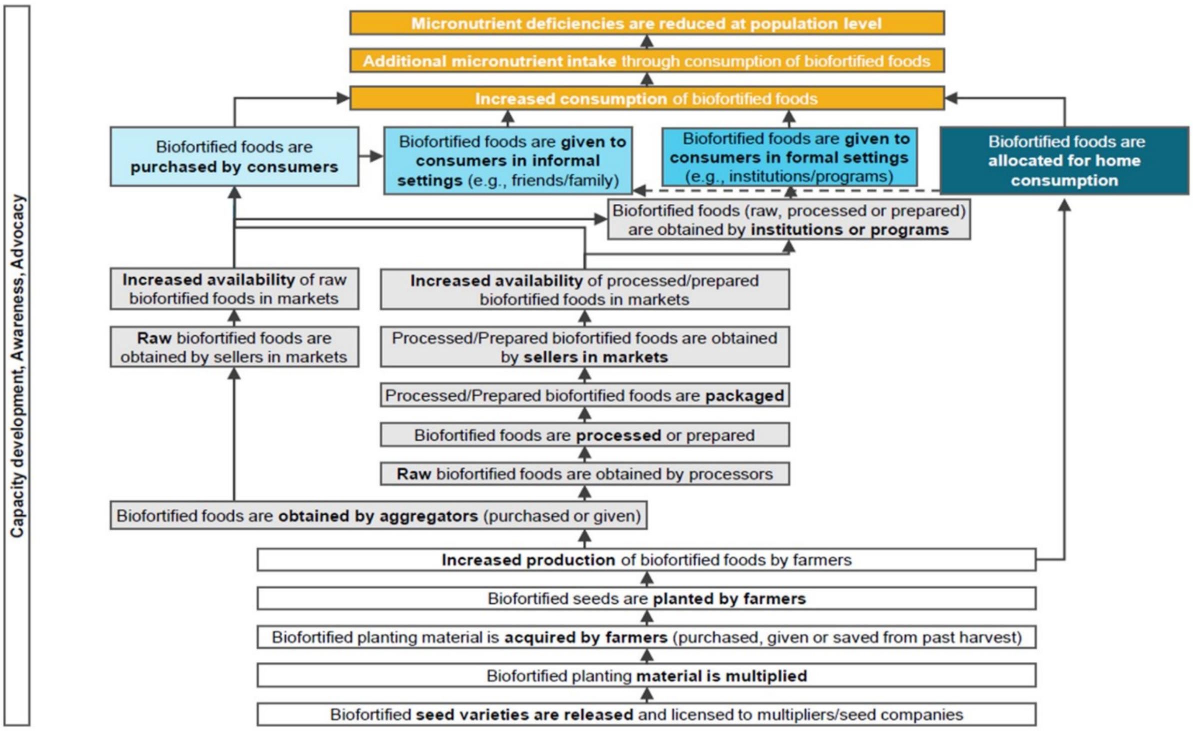

Figure 1. 1 Scaling path for biofortified crops: Adopted from HarvestPlus, 2019

The seeds produced must be delivered to farmers. Foley et al. (2021) noted two main channels for delivering planting material to farmers. First, the seed multipliers use their distribution channels, like agrodealers, to sell planting materials. This is seen in India, Malawi and Zambia with vitamin A maize and Iron pearl millet. The second channel is social delivery, which involves NGOs and the government procuring and distributing the planting material to farmers. The key to the rapid increase in farmers that grow biofortified crops is farmer-to-farmer sharing. This accounts for most of the farmers growing biofortified crops. After the planting material is delivered to farmers, the crop is grown by small-scale and large-scale farmers. Evidence shows that adoption of the biofortified crop varieties depends on seed packet size, information dissemination, access to extension, education, and experience (Vaiknoras et al., 2022; Telsma et al., 2021). Net seller of biofortified crops sells their produce to rural, urban, and peri-urban consumers. Utilization of biofortified crop products can be enhanced by awareness creation. Mulwa et al. (2022) have shown that nutrition awareness increased the utilization of OFSP in fragile communities.

Integrating biofortification into national and international policy agenda aims to increase biofortified crop varieties' productivity and reduce micronutrient deficiency (Evenson and Gollin, 2003; Alston et al., 2000). Evidence has indicated that several national governments have included biofortification in their policy documents. For example, Foley et al. (2022) noted that India incorporated biofortification in the 2016 Sustainable Nutrition Revolution policy. In Uganda, biofortification has been integrated into national agriculture and health programs, including the Micronutrient Deficiency Control Program (2013-2019), the National Strategic Plan of Action for Nutrition (2014-2019), the National Policy on Food and Nutrition (2016), and the Agricultural Sector Food Security and Nutrition Strategy (2016- 2025). The effect of this policy inclusion on agricultural productivity needs to be explored. Studies on policy reforms have focused on the seed sectors that call for improvement in enforcement (Bagamba et al., 2022; Gatto et al., 2021; Alston et al., 2000).

1.2 The transaction cost theory

The transaction cost theory forms an important theoretical foundation for this thesis, especially in chapters three and four. The transaction cost framework is a popular framework in agricultural and rural development. Williamson (1985) initially developed the theory to study firms' transaction costs. The later extensions of the framework analyze the rationale behind economic exchanges, as in fresh vegetable value chains, rural service delivery (Birner and von

Braun, 2009), and veterinary service delivery (Ilukor et al., 2015), among others. "Transaction cost economics suggests that firms should select the governance arrangement that minimizes the costs of economic exchange" (Williamson, 1985). The cost-effectiveness of the governance structures determines their emergence. Figure 1.2 illustrates the cost-effectiveness of governance structures in the marketing of crops. A governance structure that offers higher prices to farmers for iron beans and or OFSP at a lower cost is cost-effective. In the literature, hypothetical cost curves are essential to analyze the comparative advantage of different governance structures (Birner and von Braun, 2009). On the vertical axis are the total costs instead of transaction costs. The attributes of the transactions, which influence the comparative advantage of different governance structures, are displayed on the horizontal axis (Williamson, 1985).

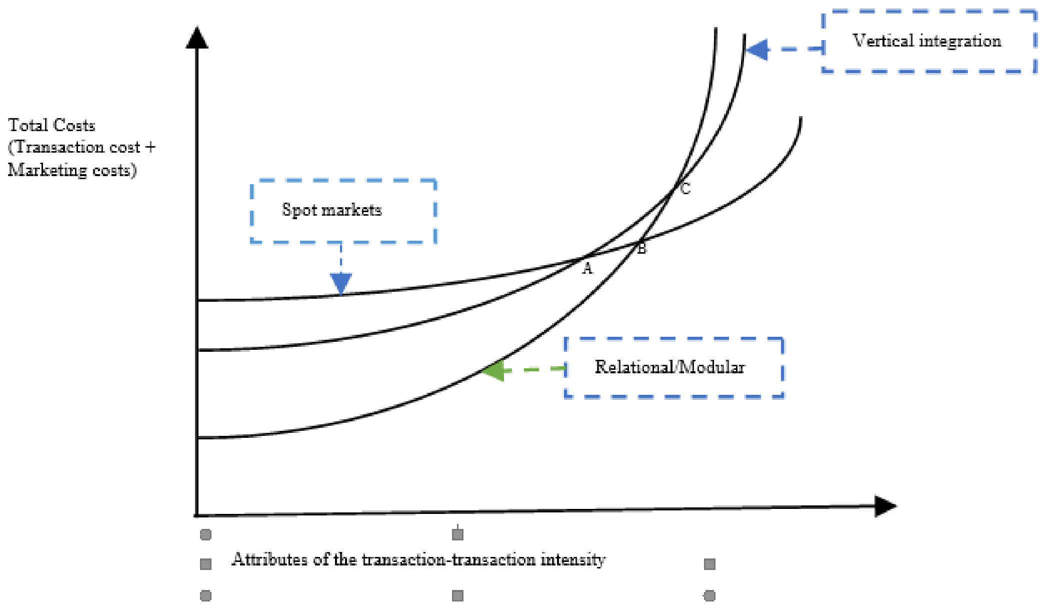

Figure 1.2 Transaction attributes and system cost effectiveness
Source: Adapted from Birner and Braun (2009, pp292)

Various governance structures can be found in value chains, ranging from spot markets to vertically integrated systems (Eaton et al., 2008). Following Williamson (1991), governance structures are institutions where rules of the game exist, and economic agents align themselves with the institutions to optimize revenues (Silva and Saes, 2007). Therefore, shifting from a spot market to vertically integrated systems via different hybrids (relational and modular)[1]

[1]spot market- farmers sell to conventional buyers, modular-farmers are organized in cooperatives, and relational- farmers sell to aggregators (Kwikiriza et al., 2018).

entails increasing administrative control, diminishing autonomous adaptation, and increasing coordinated adaptation (Williamson, 1991). In Figure 1.2 above, the slope of the hypothetical cost curve for spot markets rises more gradually than the slope for alternative governance structures as the attribute level increases (moving from left to right on the horizontal axis). Points A, B and C are the equilibrium positions, while the area above point A is the relative advantage of the spot markets to the vertically integrated system. Similarly, the area above point B is the comparative advantage of the spot markets to the hybrid system. The area above point C is the comparative advantage of the hybrid system over the vertically integrated system. In scaling of biofortified crops, many governance structures have emerged either enhanced by development partners or natural participation of private sector in the value chain. For example, biofortified crops can be sold in the spot markets or modular or relational governance structures evolve.

1.3 Problem statement

Despite the current interest in scaling innovations, only a few methodological studies have shaped the discourse on the subject matter (Gebreyes et al., 2021; Sartas et al., 2020; Seerp et al., 2016) and some empirical ones (Van Loon et al., 2020). On prices, the past literature documents the cost of healthy diets and changes in prices of food commodities (Alemu et al., 2019; Dizon et al., 2019; Barosh et al., 2014). Literature on long-term trends in prices of micronutrient-dense foods and starchy staple foods is very scarce because of data limitations. As the data for prices on primary and manufactured goods have been collected for many decades, the emerging price gap between primary and manufactured goods or the so-called deteriorating terms of trade for raw materials, including agricultural products, has been well documented (Baffes and Etienne, 2016; Ocampo and Parra, 2003). However, empirical evidence on long-run price trends for food rich in micronutrients as opposed to food rich in calories has not been provided so far. Such prices, however, matter as they both influence production and consumption as well as domestic and international trade thus may also influence scaling.

Several studies have found governance challenges in programs implemented at scale (McKeon, 2021; Schut et al., 2020; Birner and Sekher, 2018; Behnassi and Yaya, 2011). For example, Van Loon et al. (2020) analyzed the scaling of mechanization services in sub-Saharan Africa, Asia, and Latin America. Examples of the challenges identified by their paper included entry and exit barriers to trade, high taxes, and financing inefficiencies in scaling tractor services. Daum and Birner (2015) identified similar governance challenges regarding mechanization in

Ghana. At the global level, Behnassi and Yaya (2011) alluded to governance challenges in the food supply chain resulting in inadequate access to food. The reasoning behind this is that the governance challenges identified in these studies differ depending on the nature of the program, the actors involved, and the program implementation strategies, affecting its effectiveness (Birner and Sekher, 2018). Lastly, contracts have shown mixed results on farmers' outcomes especially input use, income, and welfare (Girma and Gardebroek, 2015; Bellemare, 2012; Maertens and Swinnen, 2009; Bolwig et al., 2009; Leung et al., 2008). Limited papers have explored the effect of contracts on the performance of aggregators, retailers, and processors[2] in the staple crop value chain.

1.4 Specific objectives

A growing interest has emerged in scaling interventions to reduce micronutrient deficiency among government policymakers and partners amidst price shocks, governance challenges, and environmental shocks. First, the existing food price literature has focused on the cost of micronutrient-dense and starchy staple foods, as well as price increases in various commodities. However, the long-term price growth of micronutrient-dense and starchy staple foods, as well as the price growth gap between micronutrient-dense and starchy staple foods, has received little attention. Second, many institutions are involved in scaling biofortified crops, and institutional governance challenges have been identified as critical bottlenecks. However, little is known about the fundamental nature of governance challenges and the extent to which they manifest. As a result, the governance challenges are not thoroughly researched in order to provide policy direction. Development partners and governments have advocated for the involvement of aggregators, processors, and retailers in scaling staple crops. Yet no information is available on the distribution and performance of aggregators, processors, and retailers. The objectives of this thesis are: 1) to analyze the long-term prices of micronutrient-dense foods and starchy staple foods in developing countries, 2) to examine the governance challenges in scaling biofortification program in Uganda and 3) to determine factors that are associated with distribution and performance of aggregators, processors, and retailers in vitamin A cassava food chain in Nigeria.

[2] Aggregator primarily buys biofortified crop produce from farmers, bulks, stores and sometimes package and transports to sell in other markets. A processor mainly buys raw biofortified crop, manipulates the form of the produce, package, store and sell. They may also offer processing services to other people. Retailers purchase raw or processed biofortified crops/produce and sell them to end users called consumers.

1.5 Research topics and questions

Research topic one: Analysis of long-term prices of micronutrient-dense and starchy staple foods in developing countries.

The first topic is discussed in chapter 2 of the thesis. In this topic, we hypothesize that 1) prices of micronutrient-dense foods increase more rapidly than starchy staple foods in developing countries and 2) the price difference between micronutrient-dense foods and starchy foods widens as per-capita income grows. This hypothesis is based on the income elasticities of demand for micronutrient-rich food among low-income populations tend to be above one, and for staple food below one, sometimes even below zero. As per-capita income rises, the demand for micronutrient-rich food rises faster than that for staple food. This diverging effect is even more pronounced at a higher average income level of a country as the income elasticity of starchy food may eventually become negative while food rich in micronutrients may still have income elasticities above one. We endeavour to show that the price difference between starchy staples and foods high in micronutrients may be associated with overall income growth.

Research topic two: Understanding the governance challenges in scaling the biofortification program in Uganda.

This subject is covered in Chapter 3. The primary research questions addressed by this research topic are as follows: Who are the actors, and what role do they play in the scaling of biofortified crop programs in Uganda? What are the governance challenges, and how do they impact the expansion of biofortified crop programs in Uganda? And what are the potential solutions to these governance issues? Understanding the roles of various actors, their interests, and their resource capacity assists with the creation of appropriate institutional arrangements for scaling biofortified crop programs in Uganda and improving actor coordination (Burgos and Otte, 2009). Enhanced coordination among the actors ensures smooth scaling of biofortified crop programs and improved service delivery (Vallat and Mallet, 2006). This chapter applies the Process Net-Map tool to identify networks of actors, problem areas, and possible strategies to solve these problems using a case study of Uganda.

Research topic 3: Distribution and performance of aggregators, processors, and retailers in Nigeria's vitamin A cassava food chain.

The topic is dealt with in Chapter 4. The main research questions are: what factors influence the concentration of aggregators, processors, and retailers in Nigeria's vitamin A cassava food chain? Do contracts determine the performance of aggregators, processors, and retailers in Nigeria's vitamin A cassava food chain? This topic was motivated by transaction costs theory. According to transaction cost theory (Williamson 1979), the optimal organizational structure maximizes economic efficiency by minimizing exchange costs. According to the theory, each type of transaction incurs coordination costs for monitoring, controlling, and managing transactions. The chapter hypothesizes that supply, demand, and institutional factors influence value chain actor concentration. Contracting value chain actors have lower costs per kilogram and price margin per kilogram.

1.6 Data and methods

Data for this cumulative thesis comes from various sources. Time series data from the International Monetary Fund (IMF), the Global Information and Early Warning System on Food and Agriculture (FAO-GIEWS), and the World Bank are used in Chapter 2. First, monthly IMF time series price data has nominal prices for various grains, animal products, fruits, and vegetables. This data set includes export prices such as the cost of winter wheat exported from the Gulf of Mexico free on board (FOB). Second, the FAO-GIEWS price series are monthly nominal prices for 90 countries of micronutrient-dense and starchy staple food commodities. The data also includes the corresponding real prices that have been deflated by the consumer price index (FAO, 2020). Finally, the World Bank provides data on GDP, purchasing power parity per capita in dollars, real diesel prices per litre in dollars, and average bank lending interest rates (percentage).

In chapter 3, we used data collected between April 2021 and December 2021 using Process Net-Map and field lab experiments in 10 districts in Uganda: Gulu, Amuru, Omoro, Mbale, Kamuli, Bukedea, Serere, Ngora, Hoima and Kakumiro. The districts were selected based on the delivery footprint of HarvestPlus, different agroecological zones and the concentration of value chain actors. HarvestPlus has worked in these districts for over ten years, promoting iron beans and OFSP production and consumption under different projects. A total of 63 Process Net Maps were conducted, 32 for iron beans and 31 for the OFSP. The field lab experiment included 85 farmers, with 72% of them being female.

Analysis in chapter 4 uses monitoring data collected from HarvestPlus on aggregators, processors, and retailers of vitamin A cassava, Living Standards Measurement Study (LSMS) data for 2018 in Nigeria, Global Weather Database and Nigeria Administrative Division. The annual data collected by HarvestPlus aimed to assess the outcome indicators, including throughput, sales, prices, variable costs, and contracts for vitamin A cassava and Vitamin A maize (HarvestPlus, 2022). The three rounds of data were collected from aggregators, retailers, and processors in 2019, 2021 and 2022. The first round, collected in 2019, aimed to map Nigeria's vitamin A value chain actors. About 850 VCAs were listed (149 aggregators, 411 processors and 300 retailers). A random sample of value chain actors for the second and third-round data collection in 2021 and 2022 was constructed based on the mapping exercise of 2019. A panel of 66 aggregators, 62 retailers and 63 processors were interviewed in 2021 and 2022. Data was collected on socioeconomic characteristics, throughput, variable costs, prices, participation in contracts and access to credit. The LSMS data set is a nationally representative data set collected from 743 LGAs covering agriculture, food security, credit, non-farm enterprises, labour, shocks, consumption, and expenditure. The data from HarvestPlus was georeferenced at the local government area (LGA) level using the latest GIS vector data.

1.6.1 Causal models and estimation

Estimating the impact of treatments, for example, information provision, contracts, and income, on several outcomes are the core of this dissertation. The easiest way to determine the effects of, for example, contracts on cost per unit output would be to compare the mean outcomes of aggregators, retailers, and processors with and without contracts. However, aggregators, retailers and processors with contracts will likely be systematically different from those without contracts due to selection bias and endogeneity. Selection bias may occur for the following reasons (Laure, 2007). First, the listing of aggregators, processors and retailers may not be comprehensive, and some of them may not be included in the sample. Secondly, participation in the biofortification program and contract is not random and thus based on some criteria. Lastly, the characteristics of projects is that beneficiaries are not assigned at random to treatment or control groups. As such, the error term is correlated with program participation. (Wooldridge, 2008).

“Endogeneity may be caused by omitted variable bias, measurement error and simultaneity” (Wooldridge, 2008). The relationships between the treatments and outcomes may be biased by confounding factors, thus under or overestimating their influence. Confounders can be both time-variant and time-invariant. Prior treatment participation affects the effect of time-variant confounders, whereas the impact of time-invariant confounders is unaffected by initial treatment usage (Schuler and Rose, 2017). The treatment variables in this thesis, like training and contracts, will likely be endogenous with the outcome variables. As a result of these considerations, attributing observed differences in unconditional means as "impact" would lead to incorrect conclusions about treatment effects. As a result, estimating impact is more difficult than measuring the difference between the treatment and control groups in terms of the outcome of interest. A number of models have been used to address endogeneity in impact evaluation, for instance, instrumental variable models, endogenous switching models, propensity score matching, double robust estimation and correlated random effects models. The different methods for addressing endogeneity have different limitations; for example, propensity score matching estimates may be biased when the sensitivity of the results is not checked. In this thesis, we discuss the correlated random effects model.

Correlated random effects models are an extension of the random effects model for panel data analysis that controls for omitted variable bias. Though fixed effects perform better than the random effects model because it can control the level 2 variable, it still has challenges of not estimating variables that do not vary within clusters (Wooldridge, 2010). It has been proposed to estimate within effects in random-effects models to avoid this problem (Wooldridge, 2010). The correlated random-effects model, like the hybrid model, allows for the inclusion of level 2 variables and can be used with generalized estimating equations. An augmented regression test can also be performed (Jones et al. 2007). The correlated random-effects model relaxes the assumption that there is no correlation between level 2 error and level 1 variables. Any correlation between this variable and the level 2 error is corrected by the cluster averages. Including the cluster means of a group 1 variable in a random-effects model is an alternative to cluster mean centering (Halaby, 2003).

1.6.2 Time series models and estimation

Two major time series analysis problems relate to this thesis: non-stationarity and structural breaks. Many time series techniques assume that the data are stationary and no structural break. A stationary process has the property that the mean, variance and autocorrelation structure do not change over time. A structural break occurs when a time series abruptly changes at a particular point in time. This change could be a difference in the mean or a difference in the other parameters of the process that generates the series (Stock and Watson, 2003). The model's coefficients may not be constant across the entire sample. If the model describing the historical data differs from the current model, forecasting becomes difficult. We solved the problem of non-stationary price series for commodities by differencing. Differencing can aid in the stabilization of a time series' mean by removing changes in the level of the time series, as well as eliminating (or reducing) trends and seasonality (Stock and Watson, 2003). Bastianin et al.

(2016) found structural break in their analysis of price connection between crop and ethanol. Structural breaks may be caused by trade policies, weather, and war shocks (Perez et al., 2017). We control for the known structural break in 2008 using dummy variables in the time series. The dummy variable approach does not involve breaking the data and can be used to determine the importance of policy actions.

1.7 The structure of the thesis

The thesis structure is as follows: Chapter 2 presents the analysis of long-term prices of micronutrient-dense foods and starchy staple foods in developing countries. Chapter 3 examines the governance challenges in scaling the biofortification program in Uganda. Chapter 4 examines the distribution and performance of aggregators, processors, and retailers in Nigeria's vitamin A cassava food chain. Chapter 5 discusses the results and data limitations and offers policy recommendations.

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Chapter two

Analysis of long-term prices of micronutrient-dense and starchy staple foods in developing countries

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Abstract

The continued price increase of food commodities has long been a concern to academia and policymakers because of its substantial impact on poor consumers. Existing literature has concentrated on the cost of micronutrient-dense and starchy staple foods and the price rise in different commodities. Yet, the long-term price growth of micronutrient-dense and starchy staple foods and the price growth gap between micronutrient-dense foods and starchy staple foods have not been given much attention. The paper aimed to estimate the long-term trends in prices and volatility of micronutrient-dense and starchy staples and identify factors that have sustained the growth in prices of food commodities in developing countries. We have used the autoregressive and panel autoregressive distributed lag models to analyze the trends in relative prices and the effects of income growth. The results showed that micronutrient-dense food prices in real terms grew on average by 0.03% per month more than starchy staple food prices, with the expectation of a 12% growth gap in the next 30 years. The volatility of micronutrient-dense food items exceeds starchy staple foods in most domestic markets. Also, the prices of micronutrient-dense foods were more volatile in international markets than in most developing countries. Income growth in developing countries was one of the factors that contributed to the declining relative price of micronutrient-dense food commodities. Other factors, such as the high production of staple foods and price stabilization policies, may have caused price trends to persist. Policies that enhance price stabilization for micronutrient-dense foods, supplementation, fortification, dietary diversity, and nutrition-sensitive interventions such as biofortification may be adopted in developing countries.

Keywords: food price, micronutrient-dense and starchy staple foods, price trend, price volatility.

2.1 Introduction

Prices of food commodities have continued to increase over the years. World food prices doubled from 59 in January 2000 to 112 in January 2020. For instance, in developing counties like Uganda, prices of major food items such as beans, cassava, and bananas increased by 4%, 18%, and 300% between 2008 and 2020, respectively (FAO, 2020). Global food commodity prices are partially transmitted to domestic markets (Minot, 2010). The rise in prices affects the welfare of poor consumers in developing countries. Mbegalo and Yu (2016) showed that price spikes resulted in more households slipping into poverty in Tanzania. Another effect of price rise is increased stunting levels among children below five years (Chibuye, 2015; Lyu et al., 2015; Heady and Alderman, 2019). Poor households respond to price changes by prioritizing the consumption of starchy staple foods over micronutrient-dense diets. The families would reduce buying animal source foods, vegetables, fruits, and pulses and purchase cereals and tubers rich in carbohydrates. Still, Block et al. (2004) study demonstrated that mothers in poor households reduce the frequency and quantity of food eaten and feed their children when rice prices increase. The effects of coping behaviour of families when the price changes are seen in the wasting of mothers and reduction in the blood haemoglobin levels in children under five years (Block et al., 2004). French et al. (2019) found that low-income households had a lower healthy eating index than their higher-income counterparts.

Low-income households can also benefit from increasing food prices by producing and consuming micronutrient-dense foods. Magrini et al. (2016) proved that farmers with starchy staple food crops in sub-Saharan Africa respond to price signals by adjusting their acreage, production, and market supply. Ntakyo and van den Berg (2019) showed that Ugandan households that produced rice for the market had lower calorie intake. These examples point to reduced quantities available for consumption when prices increase for starchy staple foods, which might be the case with micronutrient-dense foods.

One of the reasons why low-income households are affected most by price increases is the differential income elasticities of food commodities (Wood et al., 2009; Subramanian and Deaton, 1996; Bouis, 1992; Bouis and Haddad, 1992). Engel had initially postulated this relationship between household income and expenditure on non-food and food commodities. Several studies have expanded Engel's law to analyze the share of household income allocated for micronutrient-dense food and starchy staple food commodities. These studies have concluded that households spend more on starchy staples than on micronutrient-dense when prices of food commodities increase (Nsabimana et al., 2020; Dizion et al., 2019; Amfo et al., 2019). Though these studies prove that income affects commodity prices, some caveats exist. First, the effect of income on the costs of commodities in these studies are specific to food commodity, for instance, vegetable, cereals, and roots, which does not provide an aggregate picture of starchy foods. Secondly, the studies consider household characteristics in their analysis. Therefore, in these studies, the effect of income on relative prices of micronutrient-dense food is implied.

Past studies on healthy foods that involve price analysis have concentrated on the availability and affordability of food diets (Alemu et al., 2019; Dizon et al., 2019; Barosh et al., 2014) and on the price changes of food items from one period to another (Meenakshi, 2016). These studies have found that healthy diets are costlier than calorie-rich diets. At the same time, studies on the relative prices of healthy food diets (Bachewe et al., 2019; Heady and Alderman, 2019; Wiggins et al., 2015; Rao et al., 2013) have concluded that nutritious diets are more expensive than starchy staples, with few caveats. First, the studies are country specific (Bachewe et al. 2019; Wiggins et al. 2015) and compared specific food item price increases in meat against rice prices (Meenakshi 2016). Secondly, some studies focus on diets, not food commodities and are based on cross-sectional data sets where the researchers have not analyzed the trends. Lastly, some studies use simple trend analysis, which does not consider the static properties of data. A more extraordinary rise in the price of micronutrient-dense food commodities than starchy staple food commodities may result in nutrition challenges like micronutrient deficiency. We extend the literature on the cost of micronutrient-dense diets by estimating the trends and volatility in prices of micronutrient-dense and starchy staple food items using time series econometric methods that address static data problems at the national and global levels.

In this paper, we answer the question, "do prices of micronutrient-dense food commodities grow faster than starchy staple food items, and can income explain the variation in relative prices of micronutrient-dense food items”? Section 2.2.1 offers the data sources for retail prices for several micronutrient-dense and starchy staple food items in 23 developing countries. In section 2.2.2, we create the methodology to analyze time-series data to test the hypothesis that the prices for starchy staple food items in developing countries increased less than micronutrient-dense food items over the same reference period. Our analysis finds that micronutrient-dense food prices grew on average across all countries by 0.03% per month, more than starchy staple food prices. In section 2.4, we identify several theoretical reasons why prices for micronutrient-dense foods have increased more than starchy staple food in the past and why it is likely that this trend will persist in the future. The observed differential price trend for micronutrient-dense food has implications for the fight to eradicate hidden hunger and calls for sustainable long-run investments in agri-food value chains to lower the costs for bioavailable micronutrients for human consumption.

2.2 Methodology

2.2.1 Data and sources

We used the publicly available data set for micronutrient-dense and starchy staple food commodities to analyze the relative price growth of micronutrient-dense food commodities from three sources. These sources are International Monetary Fund (IMF), Global Information and Early Warning System on Food and Agriculture (FAO-GIEWS), and World Bank (table 2.1). Preferably, a long period should be more than ten years where the effect of weather, supply, and demand shock transmitted from international trade, such as the 2007/08 food crisis, or financial markets, like the 2008 global financial crisis or the 1997 Asian financial crisis, are smoothened.

We modified Headey and Alderman's (2019) categorizations of foods in our study into starchy staple foods and micronutrient-dense foods since we are interested in the overall price trends of the two groups. The starchy staples include cereals and tubers dense in calories but generally low in micronutrients and quality proteins, while micronutrient-dense foods consist of vegetal and animal-source foods. As a result of the inadequate long-term price data, most vegetal foods rich in vitamins and minerals, like vegetables and fruits, were not used in the analysis except legumes and nuts (rich in protein). The animal-source foods are rich in high-quality protein and bioavailable iron, choline, and vitamin B-12.

The IMF data set contains monthly nominal prices for several grains, animal products, fruits, and vegetables from January 1980 to May 2020[3] (IMF, 2020). This data set records international export prices, for example, winter wheat free-on-board prices shipped from the Gulf of Mexico. Different from the IMF data set, the FAO-GIEWS price series are country-specific[4]. It contains monthly nominal prices of micronutrient-dense and starchy staple food commodities for 90 countries. The data also lists the corresponding real prices deflated by the

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[3] One can access IMF data from: http://www.imf.org/external/np/res/commod/index.aspx
[4] http://www.fao.org/giews/pricetool/

consumer price index (FAO, 2020). The prices were collected from major cities/ towns at the retail or wholesale level. Our hypothesis focused on the consumer level, so we used retail prices in our analysis. The commodities' prices were recorded as national average or specific market location prices. We used the average national price for a particular crop and month as a default. Otherwise, we computed the average national price as a simple arithmetic average from the market prices for a specific commodity and month. FAO-GIEWS did not provide information on the different markets' sizes; therefore, a weighted price average was not feasible to calculate. The data set has different time lengths; for example, for India, data was available from January 2000 until May 2020, while Uganda's data was available from January 2006 until May 2020.

Of the 90 countries in the FAO-GIEWS database, 47 countries only have prices for starchy staple food commodities. Hence, we could not use these countries' data to test the hypothesis as prices for micronutrient-dense food commodities are missing. We are left with 45 countries, where six countries were dropped because the time series for which prices for all food commodities were observed is less than ten years, considered a minimum length of the reference period. These six countries are Cote devoir, Russia, Japan, Iraq, Honduras, Yemen, Egypt, and Argentina. In Angola, milk was the only micronutrient-dense food item for which a price was recorded. Given a low per-capita food consumption of milk of only 11.2 kilograms per capita in 2011 (FAOSTAT, 2020), milk was unlikely to be a significant contributor of micronutrients to the diet of poorer segments of the Angolan population. Therefore, we dropped Angola as well. In 7 countries (Honduras, Somalia, Mexico, Guatemala, Rwanda, Thailand, and Tanzania), we observed the prices of micronutrient-dense food commodities at the wholesale level. We excluded these seven countries from the analysis because we focused on retail prices. In contrast, prices for starchy staple foods were recorded at the wholesale and retail levels. Given the possibility of market imperfections, price movements in wholesale markets may not correlate well with price movements in the retail market. Lastly, we left four countries (Saudi Arabia, Israel, Panama, and Chili) out of the final set as they are classified as high-income countries.

Hence, a total of 23 countries remained for the analysis. The 2018 population of the 23 countries constitute 24% of the world population. Table 2.1 shows the starchy staples and micronutrient-dense food commodities for which prices were recorded in 23 countries during a specific period. The period for which recorded prices may differ by commodity within each country. Table 2.1 only lists the period for which prices of all items listed for a specific country are recorded in the dataset. The time series length varies from 12 years for Uganda to 20 years for Tunisia. Table 2.1 also lists the international prices recorded by the IMF for wheat, rice, maize, chicken, pork, fish, and beef. These nominal IMF prices for micronutrient-dense and starchy staple food items have the most prolonged reference period of 30 years. We used the consumer price index from the United States Department of Labor to calculate the real international prices.

The last data comes from World Bank on the gross domestic product (GDP), purchasing power parity per capita in dollars, real diesel prices per litre in dollars, and average bank lending interest rates (percentage)[5]. More extended time series data for the parameters mentioned are available than the FAO-GIEWS price series. Still, we used data comparable to the time series period in the FAO-GIEWS.

[5] https://data.imf.org/regular.aspx?key=61545867

Table 2.1 Period for starchy staples and micronutrient-dense food prices by country

Country	Period	Number of months	Food commodities
Azerbaijan	January 2006 to April 2020	172	Starchy staples: wheat, maize, potatoes. Micronutrient-dense: beef, milk, mutton
Burundi	January 2006 to April 2020	172	Starchy staples: maize, cassava, rice. Micronutrient-dense: beans
Botswana	January 2007 to May 2020	161	Starchy staples: maize, sorghum, rice, wheat Micronutrient-dense: beef, milk
Cameroon	January 2005 to March 2020	183	Starchy staples: bananas, maize, rice, cassava, wheat, and potatoes. Micronutrient-dense: beans
Costa Rica	January 2000 to May 2020	245	Starchy staples: rice, maize, wheat. Micronutrient-dense: beans
Kazakhstan	November 2005 to May 2020	175	Starchy staples: potatoes, wheat. Micronutrient-dense: beef, milk.
Dominican Republic	January 2006 to May 2020	173	Starchy staples: maize, rice. Micronutrient-dense: beans, chicken
El Salvador	January 2006 to April 2020	172	Starchy staples: maize, rice, sorghum. Micronutrient-dense: beans
Georgia	January 2004 to May 2020	197	Starchy staples: wheat, potatoes. Micronutrient-dense: beef, chicken, pork
Kyrgyzstan	January 2005 to May 2020	185	Starchy staples: potatoes, wheat. Micronutrient-dense: beef, mutton
Haiti	January 2005 May 2020	185	Starchy staples: Maize, rice, sorghum. Non-staple: beans
India	January 2000 to May 2020	245	Starchy staples: Rice, potatoes, wheat. Micronutrient-dense: Chickpeas and milk
Mauritania	October 2003 to May 2020	200	Starchy staples: wheat, rice. Micronutrient-dense: beef, camel meat
Mongolia	January 2007 to May 2020	161	Starchy staples: Potatoes, rice, wheat. Micronutrient-dense: beef, mutton
Nicaragua	September 2007 to April 2020	152	Starchy staples: rice, maize. Micronutrient-dense: beans
Peru	January 2000 to May 2020	245	Starchy staples: maize, rice, wheat, potatoes Micronutrient-dense: chicken
Samoa	November 2005 to April 2020	174	Starchy staples: rice and taro Micronutrient-dense: chicken
Tajikistan	January 2006 to April 2020	175	Starchy staples: wheat, potatoes Micronutrient-dense: beef
The Philippines	January 2000 to May 2020	245	Starchy staples: rice, maize. Micronutrient-dense: Pork
Tunisia	January 2000 to April 2020	244	Starchy staples: wheat, rice, maize, potatoes. Micronutrient-dense: beef, mutton, chicken, milk, chickpeas, fish
Uganda	July 2008 to May 2020	143	Starchy staples: matooke, cassava. Micronutrient-dense: beans
South Africa	January 2008 to March 2020	172	Starchy staples: wheat, rice, maize, potatoes Micronutrient-dense: beef, chicken, fish
International Prices	January 1980 to May 2020	437	Starchy staples: wheat, rice, maize Micronutrient-dense: chicken, pork, fish, beef

2.2.2 Empirical specification

To test whether prices of micronutrient-dense food grow faster or are more volatile than starchy staple foods, we used two methods to estimate volatility and price growth. Price growth is the variation in prices from one month to another, also known as the "trend of the price series," while price volatility is the variation overtime period (Zeller et al., 2018; Minot, 2014). We first cleaned the data downloaded from FAO-GIEWS, IMF, and World Bank. We filled the missing prices with predicted values from a linear regression of prices against time as it preserves the relationship. Next, we calculated the price index for micronutrient-dense and starchy staple food groups using the Laspeyres index formula (Kalkuhl et al., 2016; Brown et al., 2012). Laspeyres index uses the base prices as the point of reference, and it has greater flexibility in calculating index numbers, and quantities of each food item bought are not required (Diewert, 2001). The price index for each of the two food categories was computed as follows;

$$P_t = \frac{\sum_1^n p_{i,t} w_i}{\sum_1^n pb_{i,t} w_i} * 100 \quad (2.1)$$

where the P_t is the price index of a food group in month t; $p_{i,t}$ is the price of commodity i in month t; n is the number of food commodities for which the price index is computed, and $pb_{i,t}$ is the price at the base month. The base month is the first month of the period, as shown in Table 2.1. By definition, the price index P_t for t=0 has a value of 100 for the base month, w_i is the weight for a specific commodity i. The price of each food commodity was weighted using the proportion calculated using per capita food supply. The weighting accounts for a particular food item's contribution to a group's price since food supply drives prices. We obtained the country-specific per capita energy supply data for a specific food item from the food balance sheet of FAOSTAT for 2017[6], which is the year for which data was available for all the countries in the analysis.

First, we analyzed the long-term prices of food commodities by estimating the price growth for each food group computed as the arithmetic average of the monthly percentage fluctuations in the prices following Wiggins et al. (2015). The monthly percentage changes in the prices for micronutrient-dense and starchy staple food groups were computed using the formula below.

$$a = \frac{P_t - P_{t-1}}{P_{t-1}} * 100 \quad (2.2)$$

[6]Data can be accessed from http://faostat3.fao.org/download/FB/*/E

Where α is the price change between two subsequent periods, P_t is the Laspeyres index for period t, and P_{t-1} is the Laspeyres index for the previous period t-1. Another reasonably standard measure for price growth in the economic literature is the difference in the Laspeyres price index between the base period and the month at the end of the time series of a particular food group (Bachewe et al., 2019; Kalkuhl et al., 2016). However, price growth measured using a simple arithmetic average approach may give erroneous results as commodity prices are usually non-stationary and exhibit random walk behavior.

We determined the trends in the relative prices of micronutrient-dense foods using an autoregressive model, including a trend variable while accounting for a structural break in 2008 and a seasonal effect. This model is specified below. A dummy variable for the structural break and seasons is included in the model.

$$Y_{it} = \beta_0 + \alpha t + \gamma Y_{i,t-1} + \lambda d_i + \vartheta dt_i + \Phi S_i + \mu_t \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2.3)}$$

Where α , γ , λ , ϑ Φ are the parameter estimates, Y_{it} is the price index for the food group i (micronutrient-dense food, starchy staple food, and relative food prices) at time t, d_i is the structural break dummy variable, dt_i is the interaction term between the break and time trend, S_i is the seasonal dummies. We used one lag since it gave better results than other models with many lags. Baffes and Etienne (2016), Yamada and Yoon (2014), and Erten and Ocampo (2013) have used an autoregressive model in the analysis of long-term price trends of manufactured and primary goods.

Results for the stationary test using Augmented Dickey-Fuller (ADF) are presented in table A2.3, where for example, 50% of countries' relative prices exhibit non-stationary series. The first differencing of the non-stationary series was stationary. Then we tested whether the trend coefficient for micronutrient-dense foods in the international market is more significant than that in domestic markets. The null hypothesis was that the trend coefficient in equation 4 is zero for micronutrient-dense food groups, starchy staple food groups, and relative prices of micronutrient-dense foods in each country.

Secondly, in this study, we analyzed food price uncertainty, referred to as variation over time. Brown (2012) measured volatility using the "coefficient of variation, which is the ratio of standard deviation and mean of the variable of interest." Minot (2014) noted that the calculated volatility value depends on the data length. In other words, the standard deviation becomes infinity as the length of the data reaches infinity. Using the coefficient of variation to measure price stability may give false results since it does not address the statistical challenges of time series data (Stock and Watson, 2015).

With the challenges in coefficient of variation, we used the standard deviation of returns as the most commonly used in financial markets to measure variability. The "returns" are defined as the "proportional change in commodity prices from one month to the next" (Minot, 2014). In practical terms, we computed the return as the change in the logarithm of monthly commodity prices.

Unconditional volatility= stdev(r) $\left[\sum \frac{1}{N-1}(r_t - \bar{r})^2\right]^{0.5}$ …………………… (2.4)

where

$r_t = In(P_t) - In(P_{t-1})$

$\bar{r} = \sum \frac{1}{N} r_t$

The change in the logarithm of monthly commodity prices makes the commodity prices stationary, and its standard deviation does not depend on the time series length. Any prior information about the size of the period is not necessary, and volatility was based on the available data (Minot, 2014). Additionally, we estimated the generalized autoregressive conditional heteroskedasticity (GARCH) model to determine volatility. The GARCH model is a typical technique for modelling volatility in food prices. In the GARCH model, an autoregressive process is specified for the variance, followed by a time series analysis to yield an estimate of the conditional variance of the process at each date in the time series. The GARCH model allows the "variance of returns to change over time as a function of lagged squared residuals and lagged variance" (Gilbert and Morgan, 2010; Bachewe et al., 2019). Following Gilbert and Morgan (2010); Bachewe et al. (2019), the GARCH (1,1), we specified the model as:

$h_t = \varphi + \theta_1 h_{t-1} + b_1 \mu_{t-1}^2$………………………………………………………… (2.5)

Where h_t is the conditional variance at month t, μ_{t-1}^2 is the lagged square error term φ, θ, b are the parameter estimates. Since it outperforms other models, we estimated the GARCH(1,1) model for micronutrient-dense and starchy staple food groups in all the countries (Hansen and Lunde, 2001). Calculating unconditional price volatility for micronutrient-dense and starchy staple foods involves two data sets. We test the null hypothesis that the two sets of prices have the same standard deviation in returns using *vartest.*

2.2.3 Income and the relative price of micronutrient-dense food commodities

Using a panel framework, we estimated the relationship between income and relative prices of micronutrient-dense foods. A panel autoregressive distributed lag (ARDL) models income effects on relative prices of micronutrient-dense food commodities. Pesaran and Shin (1998) have shown that the model produces consistent short-run and long-run parameters with small sample sizes and different variables' integration orders. One of the critical assumptions in the panel ARDL is cross-sectional independence among the variables. The assumption ensures estimates are consistent since cross-sectional correlations are standard features of commodity prices due to the incidence of common shocks and spatial dependence. Another challenge with the relationship between income and prices is reverse causality, which makes the estimates unreliable. Reduced-form equation models are suitable to address such problems. The studies of Pesaran and Smith (1995) have shown that panel ARDL estimates are as reliable as reduced-form models. In Baffes and Etinne (2016), panel-ARDL models were viewed as reduced-price deterministic models. Following Baffes and Etinne (2016), an error correction version of the panel ARDL model was specified as follows:

$$\Delta N_{it} = \sum_{j=1}^{p-1} \gamma_p^i \Delta N_{i,t-j} + \sum_{j=0}^{q-1} \delta^i{}_j \, \Delta X_{i,t-k} + \varphi^i\left[N_{i,t-1} - \left\{\beta_0^i X_{i,t-1}\right\}\right] + \mu_{it} \ldots\ldots\ldots\ldots\ldots \quad (2.6)$$

N_{it} is the relative prices of micronutrient-dense foods; p and q are the lags of the dependent and independent variables, respectively; X_i are independent variables, including income, interest rates and fuel prices; γ represents the short-term parameters of the lagged dependent variable; δ also refers to the short-run coefficients but of the lagged explanatory variables; φ reflects the speed of adjustment to the long-run equilibrium; β indicates the income in the long run; μ_{it} is the error term.

We explored the descriptive statistics of relative prices of micronutrient-dense foods, income, fuel prices, and interest rates for the whole data (Table A2.6). The average relative price of micronutrient-dense food was 1.083, the average gross domestic product (GDP) per capita purchasing power parity was 8,567 dollars, and average interest rates were 15%. We used pooled mean group estimator (PMG) and dynamic fixed estimator (DFE) to estimate the model's coefficients in equation 2.6. Then we tested the cross-section dependence using the Breusch-Pagan test under fixed effects and rejected the null hypothesis of cross-sectional independence.

This study's dependent variable was the relative prices of micronutrient-dense food items. The primary independent variable is income. Most studies found that income increases food prices (Baffes and Etiene, 2016; Meenakshi, 2016; Gilbert, 2010; Hochman et al., 2011). Following Baffes and Etiene (2016), we measured income as the gross domestic product (GDP) per capita purchasing purity in dollars. The purchasing power parity exchange rate is stable over time, making GDP per capita purchasing purity applicable for comparing countries' living standards. Two control variables (interest rates and fuel prices) are included in the panel ARDL as data was not readily available on stock volumes and infrastructural variables. The market lending interest rates measured as percentages in each country have heterogeneous effects on prices. While Bryrne et al. (2013); Akram (2009) found negative results. Baffes and Savescu (2014) showed positive effects of interest rates on prices. We measured fuel prices as retail pump prices for diesel per litre. Studies by Zhang et al. (2010) and Bachewe et al. (2019) have demonstrated that commodity prices are affected by fuel prices, while Reboredo (2012) did not find any relationship. Therefore, there is a lack of consensus in the literature about the effect of fuel prices and interest rates on food prices.

2.3 Results

2.3.1 Price growth of micronutrient-dense and starchy staple foods in international markets

We begin by examining long-term price trends in micronutrient-dense and starchy staple food items with prices in international markets to provide a background in interpreting trends. Since we are interested in the trend coefficient, we did not present the structural and seasonal dummy results in equation 2.3. The results indicate that micronutrient-dense and starchy staple food prices increased between 1980 and 2020. As the prices of starchy staple food increased by 0.13%, the micronutrient-dense food group's prices increased by 0.34% per month during the same period (Table 2.2). The F-statistic indicates that prices of micronutrient-dense food groups grew more than starchy staple foods at a 5% significance level. The results from relative prices of micronutrient-dense foods to starchy staples collaborate with these results. We find similar evidence of faster growth of micronutrient-dense food items over starchy staple food items (table 2.9) using a simple average of monthly price changes. Manfred et al. (2018) found that the long-term increase in micronutrient-dense foods' price over starchy staple foods was 0.1, slightly lower than what we saw in this paper.

Table 2. 2 Trend coefficient for food groups in the international market

Food groups	Coefficient	P-value
Relative prices of micronutrient-dense foods to starchy staples	-0.001 (0.001)	0.011
Starchy staples, food commodities	0.001 (0.001)	0.063
Micronutrient-dense food commodities	0.003 (0.001)	0.002
The difference in coefficient between micronutrient-dense foods and starchy staples foods	0.002	0.031

The figures in brackets are standard errors.

2.3.2 Distribution of food price trends in developing countries

The autoregressive model in equation four was estimated for relative prices, starchy staples food group, and micronutrient-dense food group. The results for the autoregressive model are presented in table 2.3. We describe the results in column four as they directly test the hypothesis that micronutrient-dense food grows faster than starchy staple foods. Generally, most countries show a negative trend in the relative prices of micronutrient-dense food items, suggesting that their prices increase more than starchy staples. The negative price trend in eight countries was significant at five or ten percent. In these countries, we found the relative prices of micronutrient-dense foods to decline between 0.01% (Tunisia) and 8% (South Africa) per month.

We found the price of starchy staple food items grows faster in Azerbaijan, Costa Rica, Kazakhstan, Samoa, and Tajikistan. Most countries where prices of starchy staples rose more quickly than micronutrient-dense foods are in central Asia. We examined the number of food commodities in the analysis. We found some countries had one food commodity in the micronutrient-dense food group, for example, beans in Burundi, compared to Azerbaijan, with more than one food commodity. It may be that countries with positive relative prices had one micronutrient-dense food in the group. Similar negative results of relative prices are found in some studies that provide evidence for the Prebisch-Singer hypothesis (Yamada and Yoon, 2014; Arezki et al., 2014). We obtained similar results when we used prices change from the base month to the last period in the time series (table A2.2) and average monthly real price percentage change (table A2.1). In both methods, the price of micronutrient-dense food items grows faster than starchy staple food items in over 60% of the countries.

We calculated the overall increase in monthly prices of micronutrient-dense foods over starchy staple foods across developing countries using average monthly real price percentage change. We weighted the average monthly growth in prices by the 2018 population of each country. Therefore, the average price of micronutrient-dense food items increased faster than starchy staple foods by 0.03 percentage points (Table A2.4). When the overall price gap in commodity prices was compounded in 30 years, it translated to 12%. With poor households consuming more starchy staples, a declining relative price of micronutrient-dense commodities would reduce their consumption of these foods and increase micronutrient deficiency.

Table 2. 3 Trend coefficient for micronutrient-dense food, starchy staples foods and relative prices

Country	Starchy staples	Micronutrient-dense foods	Relative price	Country	Starchy staples	Micronutrient-dense foods	Relative price
India	0.001	-0.001	-0.002	Peru	-0.002*	-0.001*	-0.013
	(0.001)	(0.001)	(0.002)		(0.001)	(0.001)	(0.023)
Philippians	0.001**	0.004**	-0.001*	Tunisia	0.001**	0.004***	-0.001
	(0.001)	(0.001)	(0.001)		(0.001)	(0.001)	(0.001)
Azerbaijan	-0.004	0.009	0.033	South Africa	0.068	0.004	-0.087*
	(0.009)	(0.009)	(0.040)		(0.050)	(0.011)	(0.061)
Costa Rica	-0.012*	0.005***	0.019	Samoa	0.001	0.013	0.015*
	(0.005)	(0.001)	(0.011)		(0.011)	(0.012)	(0.010)
Dominican Republic	-0.004	0.001*	-0.016*	Tajikistan	0.006	-0.003	0.003
	(0.004)	(0.001)	(0.011)		(0.013)	(0.028)	(0.009)
El Salvador	0.002	0.037*	-0.012	Kenya	-0.047*	0.013*	-0.045**
	(0.020)	(0.026)	(0.010)		(0.040)	(0.010)	(0.022)
Georgia	-0.001**	0.003*	-0.004*	Uganda	-0.006	0.007	-0.002
	(0.001)	(0.002)	(0.004)		(0.161)	(0.099)	(0.105)
Haiti	0.007*	0.004	-0.007**	Nicaragua	-0.161*	-0.152*	-0.013
	(0.003)	(0.002)	(0.004)		(0.089)	(0.099)	(0.011)
Kazakhstan	-0.009	0.007	0.015*	Burundi	0.007*	0.005**	-0.010**
	(0.013)	(0.012)	(0.006)		(0.005)	(0.011)	(0.003)
Mauritania	-0.002*	-0.004*	-0.001	Botswana	0.005*	0.005**	-0.011*
	(0.002)	(0.003)	(0.002)		(0.004)	(0.002)	(0.007)
Mongolia	-0.049	-0.056	-0.003	Cameroon	0.004	0.007	-0.001
	(0.057)	(0.053)	(0.018)		(0.006)	(0.005)	(0.002)
Kyrgyzstan	-0.009	-0.016	-0.010				
	(0.006)	(0.016)	(0.007)				

The figures in brackets are standard errors.

2.3.3 Micronutrient-dense food price growth in developing country markets and international markets.

We test the hypothesis that prices in developing markets grow faster than in international markets for micronutrient-dense foods. First, we conducted an F test for the trend coefficient from equation 2.3 to compare the growth in micronutrient-dense food groups between developing country markets and international markets. In slightly over half of the developing countries markets, micronutrient-dense food prices grow faster than global micronutrient-dense commodity prices (figure 2.1).

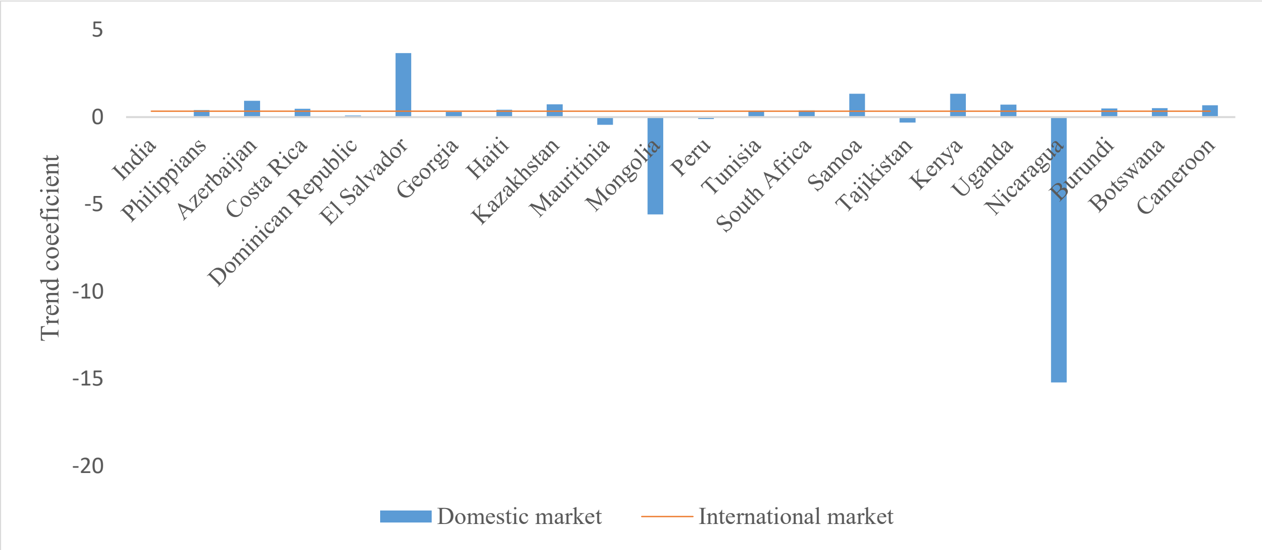

Figure 2.1 Trend coefficient for micronutrient-dense food prices in developing and international markets The F statistics indicated that the difference in the micronutrient-dense and starchy staples coefficient was significant for all domestic countries and global markets.

2.3.4 Volatility of micronutrient-dense and starchy staple foods in international markets

We first compared the price fluctuation around a long-term trend for micronutrient-dense food items and starchy staple food items in the international and domestic markets. The results show the volatility of micronutrient-dense foods was 0.003 percentage points more than the volatility of starchy staple foods (Table 2.4). Results from the GARCH model show a similar pattern (Table A2.5).

Table 2. 4 Unconditional food price volatility in the international market

Food Category	Value
Micronutrient-dense food commodities	0.031
Starchy staple food commodities	0.028
P-value	0.096

2.3.5 Distribution of food price volatility in developing country markets

Figure 2.2 presents the standard deviation of returns for micronutrient-dense and starchy staple foods in developing countries. Uganda has the highest volatility of micronutrient-dense and starchy staple foods, while Botswana has the lowest micronutrient-dense foods at 0.01. Our interest was to test whether the prices of micronutrient-dense foods are more volatile than starchy staple foods. Therefore, we did not test for the difference in volatility of the food groups across countries. We used the *vartest* in STATA to determine whether the variation in micronutrient-dense food was more than in starchy staple foods. Generally, in most countries, the variation in prices of micronutrient-dense foods was greater than for starchy staple foods (figure 2.2). The gap in the variation of prices between micronutrient-dense foods and starchy staples was significant in Dominican Republic, El Salvador, Mongolia, Mongolia, Nicaragua, and Cameroon. The analysis of volatility using GARCH showed similar results (Table A2.5). Most countries with a significant volatility gap between micronutrient-dense and starchy staple food are in Latin America, except Cameroon and Mongolia. The heterogeneous nature of volatility is no surprise, as Minot (2014) showed that the volatility of maize increased between 2003 and 2010 while it reduced for beans, millet, and rice in some African countries.

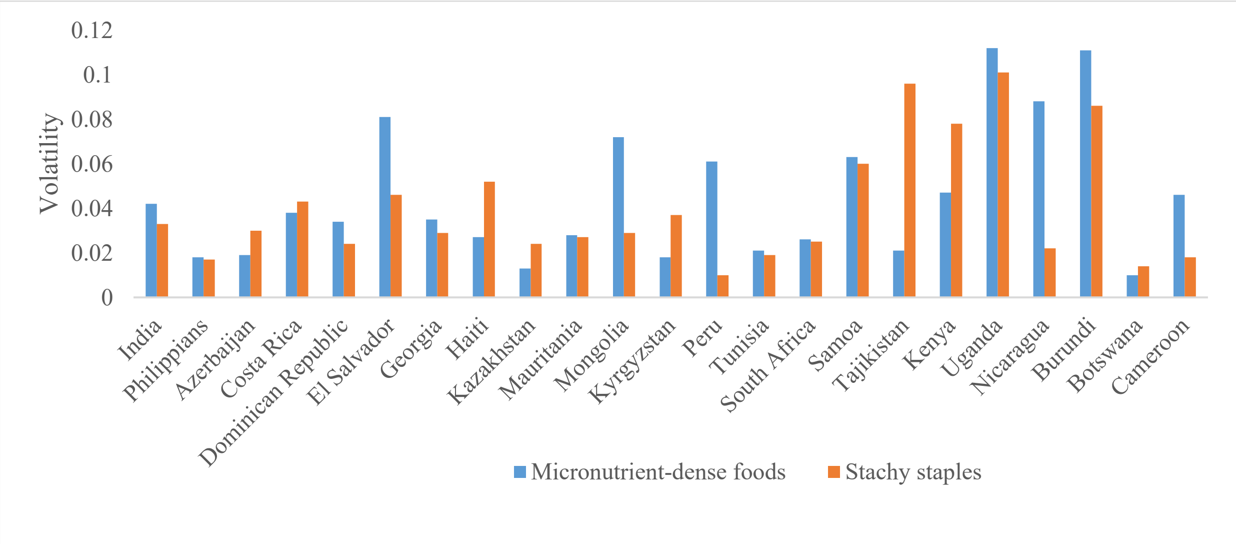

Figure 2. 2 Unconditional volatilities in food prices in developing countries by food group
The F statistics indicated that the difference in the volatility of micronutrient-dense and starchy staples was significant in Dominican Republic, El Salvador, Mongolia, Mongolia, Nicaragua, and Cameroon.

2.3.6 Micronutrient-dense food price volatility in developing country markets and international markets.

We compared the volatility in micronutrient-dense food items in developing countries with volatility for the same group in the international market. Of the 23 countries we analyzed, only two countries (Uganda and Burundi) had significantly higher micronutrient-dense food price variances than global prices. In the rest of the countries, the variance of micronutrient-dense foods was lower or equal to that of micronutrient-dense foods in international markets (figure 2.3). One of the reasons micronutrient-dense food prices in global markets may fluctuate more than in national markets is that only a tiny share of world production of micronutrient-dense foods is internationally traded. Using the coefficient of variation, Manfred et al. (2018) found that the variation in non-staple food commodities was higher in the international markets than in domestic markets. Minot (2014) showed mixed results where 62% of the rice price series analyzed were more volatile in African markets than global markets though rice is tradable like wheat and cooking oil with stable global prices.

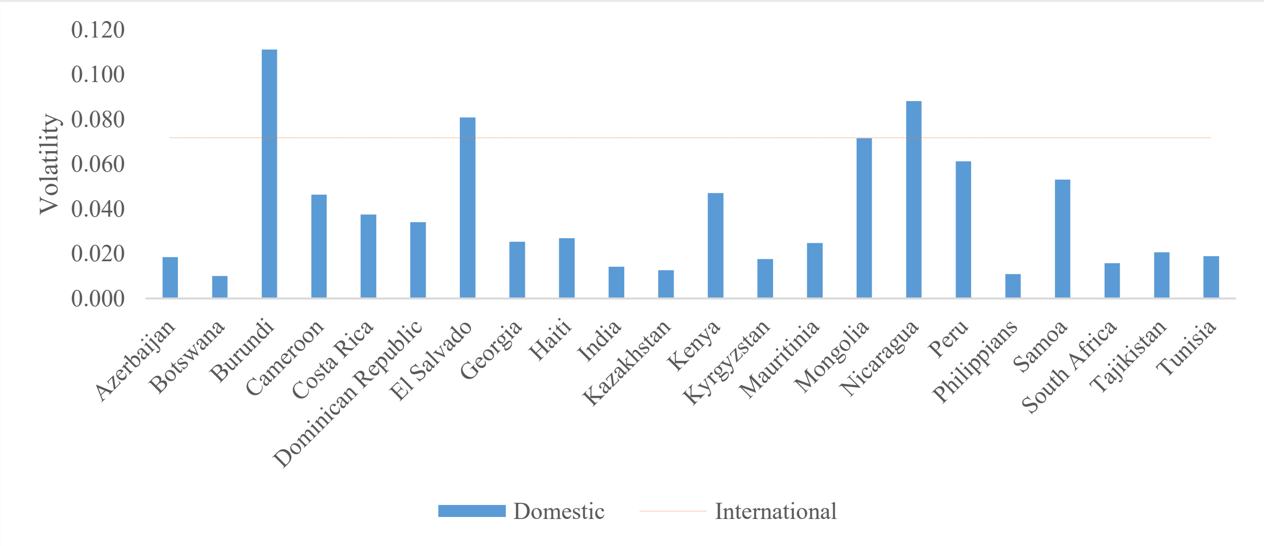

Figure 2. 3 Unconditional volatilities in micronutrient-dense food prices in developing countries and international markets
The F statistics indicated that the volatility of micronutrient-dense foods in all domestic markets was significantly lower than in the global market except in Uganda and Burundi, where it was higher.

2.3.7 The role of income growth in relative prices of micronutrient-dense food commodities.

As expected, we found a negative relationship between income and relative prices of micronutrient-dense food items (table 2.5). A one percentage increase in GDP per capita purchasing power parity leads to a 19% decrease in relative prices yearly. The results confirm studies such as Byrne et al. (2013) and Baffes and Etiene (2016) and notion when income increases, the share of income allocated for micronutrient-dense foods commodities increases. The differences in income elasticities between micronutrient-dense foods and starchy staple food items have been advanced to explain these relative price changes (Zeller et al., 2018). Studies have demonstrated that the income elasticities of micronutrient-dense food commodities are more outstanding than starchy staple food items (Colen et al., 2018; Boysen, 2016). The results also showed a significant negative relationship between interest rates and relative prices. The magnitude of the effect ranges between 0.7% and 16%, depending on the estimation method. This result is consistent with Byrene et al. (2013) and Anzuini et al. (2013), who illustrated that monetary policy was aimed at stabilizing prices. Contrary to the finding, Baffes and Etienne (2016) showed a positive effect of interest rates on the terms of trade.

In the short run, income does not seem to significantly influence the relative prices of micronutrient-dense commodities because of the stickiness of supply. Contrarily, Baffes and Etienne (2016) found a positive and significant short-run effect of income on terms of trade. On the other hand, a one percent increase in fuel prices leads to increased relative prices of micronutrient-dense food commodities by between 0.3% and 6% per year. Most of these studies established that when fuel prices rise, the prices of commodities increase (Bachewe et al., 2019; Saghaian, 2010; Gilbert, 2010) as the rise in fuel prices may be transmitted to commodities prices (Gibert, 1989; Baffes, 2007).

Table 2. 5 PMG, DFE estimates from panel ARDL model for GDP per capita and relative price

Variables	PMG (p=1, q=1)	DFE (p=1, q=1)
Long run coefficients		
ln_gdp	-0.190***	-0.076**
	(0.050)	(0.028)
ln_interest_rates	-0.166***	-0.007*
	(0.062)	(0.005)
ln_fuel	-0.022	-0.088
	(0.034)	(0.064)
ECT	-0.082***	-0.057***
	(0.014)	(0.005)
Short-run coefficients		
Δ(ln_gdp)	0.290	0.014
	(0.469)	(0.039)
Δ(ln_interest_rates)	0.065	0.005
	(0.044)	(0.012)
Δ(ln_fuel)	-0.066*	-0.003*
	(0.037)	(0.002)
_cons	0.183***	-0.018
	(0.034)	(-0.44)
Number of observations	4542	4542
Number of countries	23	23
Log-Likelihood	8942	

The figures in the brackets are the standard errors, and *, **, *** are 10%, 5%, and 1% significance levels; p and q are the lags for dependent and independent variables. ECT is the error correction term.

2.4 Discussion and implications for policy

We aimed to estimate the trends in micronutrient-dense food items and starchy staple food prices in developing countries and explore whether income can explain the relative prices of micronutrient-dense foods. The analysis shows that the prices for micronutrient-dense foods increased more than for starchy staple foods. Specifically, on average, the prices of micronutrient-dense foods increased by 0.03 percentage points per month more than the prices for starchy staple food items in domestic markets. In other words, micronutrient-dense foods would become 12% more expensive in 30 years than starchy staples. We found exceptions in Azerbaijan, Costa Rica, Kazakhstan, Samoa, and Tajikistan, where the prices of starchy foods increased more than micronutrient-dense foods. Meenakshi (2016), using nationally representative data from India, found prices for non-staples (per unit calorie) relative to cereals grew faster in India. Zeller et al. (2018) found that the prices of non-staples food items increased faster than staple food commodities.

Income growth might be the most plausible explanation for the faster rise in micronutrient-dense than starchy foods. Results from the panel ARDL model corroborates the effect of income relative prices of micronutrient dense foods, where higher per capita income negatively affects the relative prices of micronutrient-dense foods. The income elasticity of demand for micronutrient-dense food items is higher than for starchy staple food items. Colen et al. (2018) have demonstrated that animal-source foods' income elasticity is twice that of cereals. With rising GDP, the demand for micronutrient-dense food grows faster, increasing prices. In the Philippians, Dominican Republic, Georgia, Kenya and Botswana, the GDP grew by over 4% per year between 2000 and 2020 (World Bank, 2020). Despite income growth in developing countries over the years, its distribution is unequal, not benefiting the poor. In addition, countries with slow GDP growth rates (less than 2%), like Haiti and Burundi, have faced disasters and political instability that affect the supply of micronutrient-dense and starchy staples.

Generally, supply factors like the high productivity of starchy staple foods, higher cost of production of micronutrient-dense food items, and more labour intensity of micronutrient-dense food items (Gilbert and Morgan, 2010) also explain the price gap. First, many private and public investments have focused on high-yielding starchy staple crops (maize, rice, wheat). For example, over time, these high-yielding innovations have reduced production costs and increased total factor productivity for starchy staple food production, increasing market supply and dampening the long-run effect on staple food prices. Second, micronutrient-dense foods require more natural resources per unit of quantity produced. As these resources get scarcer, the production costs for micronutrient-dense food rise faster than those for starchy staple foods. The production of 1kg of beef requires five times more water than the production of 1 kg of rice[7]. Third, micronutrient-dense foods require a lot of labour (with few exceptions, such as capital-intensive agro-industrial production for poultry, beef, dairy, and pork) relative to starchy staples. As the costs of labour rise, the costs of production, processing, and preparation of micronutrient-dense food also rise. Furthermore, the higher labour intensity of micronutrient-dense food than staple food is observed in primary production and the entire value chain from farm to fork in wholesale, retail, and domestic household food preparation. Over time, these underlying trends in diverging unit production costs dampen increases in market supply for micronutrient-dense foods compared with the supply of starchy staple foods.

[7] https://www.theguardian.com/news/datablog/2013/jan/10/how-much-water-food-production-waste#:~:text=Meat%20production%20requires%20a%20much,and%204%2C000%20litres%20of%20water.

The results also demonstrate that the prices of micronutrient-dense foods are more volatile than starchy staple food items in the Dominican Republic, El Salvador, Mongolia, Mongolia, Nicaragua, and Cameroon. The following reasons explain the volatility gap between micronutrient-dense and starchy staple foods. First, unlike starchy staple foods, micronutrient-dense foods exhibit higher perishability and face higher post-harvest losses (Headey and Alderman, 2019). They also require a much higher degree of market coordination in the value chain for connecting primary producers to final consumers (Sarris, 2009; Tadesse et al., 2016; Gilbert and Morgan, 2010). Therefore, any disruption in the value chain will likely cause more pronounced price fluctuations in micronutrient-dense foods. Due to perishability and high transportation costs, the price transmission for micronutrient-dense food items is much lower than for starchy staples. These factors, in turn, ceteris paribus, cause a higher price variation among micronutrient-dense food items than starchy staple foods. Third, climate change and related weather shocks, especially in the developing world, may also be another underlying causal determinant for the higher price variation (Gaetano et al., 2018).

A comparison of the micronutrient-dense food volatility in domestic and global markets showed that prices are more volatile in international markets than in domestic markets in most countries. Global markets are less integrated for micronutrient-dense foods than starchy staples. As much as micronutrient-dense foods are traded (for example, frozen meat or mutton or high-value vegetables and fruits), the traded share is relatively low compared with global production. Sudden changes in demand and supply in major exporting or importing countries due to various factors (climatic shocks, macro-economic, financial crises, export restrictions) make international food prices volatile. In addition, speculation in global food markets through financial markets has been identified as a potential cause of price fluctuation in international food markets. However, recent studies rejected the hypothesis that speculative behavior increases food prices (Bredin et al., 2021). In countries like Uganda and Burundi, where the production of beans entirely depends on the weather, the price volatility may be greater than in international markets.

2.4.1 Policy implications and further research

Concerning policy, the above underlying hypothesized causal factors may make it plausible that prices for micronutrient-dense foods will continue to rise faster than for starchy staple foods in the near and distant future. Global and national food policy could potentially address the potential effect of a faster rise in prices by enhanced research and investment in agriculture nutrition-sensitive interventions like biofortification, high-yielding fruits, vegetables and livestock (Bouis and Saltzman, 2017; Kabunga et al., 2014; Hetherington et al., 2017); supplementation (Tam et al. 2020); and trade and or tax policies (Dizion et al. 2019; World Health Organization, 2015).

The few numbers of commodities with price data and the length of available data were a challenge for the study. Ideally, the period covered for the investigation should be the same for all countries, and the choice of food items should include all the main starchy staples and micronutrient-dense food consumed in a country. Despite the data limitations, this study still serves as a good starting point to analyze the difference in price trends between starchy staples and micronutrient-dense foods. It is essential to conduct further analysis on this topic, both on the movement and patterns with a larger sample and understand some of the underlying causal factors driving the observed differential price trend and price variation. An analysis with household consumption and expenditure survey unit values could solve limited data instead of price data from domestic markets.

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A2: Appendix for chapter two

Table A2. 1 Average monthly price percentage change by food group

Country	Starchy staples	Micronutrient-dense	Difference	Population weighted average	Country	Starchy staples	Micronutrient-dense	Difference	Population weighted average
Azerbaijan	0.264	0.090	-0.173	-0.001	Kenya	0.123	0.269	0.146	0.004
Botswana	-0.058	0.080	0.138*	0.001	Kyrgyzstan	0.071	0.129	0.058***	0.001
Burundi	0.619	1.155	0.536	0.003	Mauritania	0.004	0.050	0.046	0.001
Cameroon	0.075	0.291	0.216	0.003	Mongolia	0.180	0.419	0.239	0.001
Costa Rica	0.351	0.072	-0.279	-0.001	Nicaragua	0.110	0.374	0.264	0.001
Dominican Republic	-0.082	0.075	0.157	0.001	Peru	0.025	0.014	-0.011	-0.001
El Salvador	0.301	0.364	0.064	0.001	Philippians	0.037	0.016	-0.021	-0.001
Georgia	0.079	0.112	0.033	0.001	Samoa	0.136	-0.147	-0.283	0.001
Haiti	0.139	0.188	0.048	0.001	South Africa	0.110	0.072	-0.038	-0.001
India	0.018	0.027	0.045	0.034	Tajikistan	0.914	0.519	-0.395**	-0.002
Kazakhstan	0.132	0.228	0.095	0.001	Tunisia	-0.166	0.186	0.352**	0.002
International	0.277	0.287	0.009		Uganda	1.015	0.580	-0.435	-0.010

The difference is between micronutrient-dense food and starchy staple food. We tested the significance of the difference in average monthly growth using the Wilcoxon-Mann-Whitney nonparametric as the price increases are not normally distributed. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table A2. 2 Change in prices from the base month to the last period in the time series by food group

Country	Starchy staples	Micronutrient-dense	Difference	Country	Starchy staples	Micronutrient-dense	Difference
Azerbaijan	31.091	11.810	-19.281	Kazakhstan	16.642	31.742	15.100
Botswana	-11.469	11.234	22.703	Kenya	16.356	25.240	8.884
Burundi	32.228	57.529	25.302	Kyrgyzstan	-0.065	18.892	18.957
Cameroon	10.238	28.278	18.040	Mauritania	-6.439	4.030	10.469
Costa Rica	45.711	0.378	-45.333	Mongolia	19.802	22.972	3.170
Dominican Republic	-21.069	3.033	24.102	Nicaragua	12.158	-3.321	-15.479
El Salvador	28.054	5.385	-22.669	Peru	4.704	-52.116	-56.820
Georgia	7.022	14.434	7.411	Philippians	4.305	2.331	-1.973
Haiti	0.197	24.316	24,119	Samoa	-8.199	-64.804	-56.606
India	3.538	4.006	0.468	South Africa	10.887	8.285	-2.602
Uganda	51.451	-4.357	-55.808	Tajikistan	51.204	57.188	5.983
International	2.198	11.199	9.001	Tunisia	-56.389	33.507	89.896

The difference is between micronutrient-dense food and starchy staple food.

Table A2. 3 Augmented Dickey-Fuller unit root test for the relative price, micronutrient-dense, and starchy staple food prices

Country	Micronutrient-dense foods	Starchy staples	Relative prices	Country	Micronutrient-dense foods	Starchy staples	Relative prices
India	-2.926	-5.600***	-4.819***	Peru	-4.695***	-3.401*	-5.452***
Philippians	-3.272*	-4.345***	-3.562**	Tunisia	-4.236**	-2.276	-2,232
Azerbaijan	-2.276	-3.075	-3.081	South Africa	-3.947**	-2.237	-2.555
Costa Rica	-1.766	-1.030	-2.689	Samoa	-3.041	-3.426**	-3.632**
Dominican Republic	-4.749	-2.174	-3.389*	Tajikistan	-2.164	-4.031**	-3.930**
El Salvador	-3.280*	-3.231*	-4.128**	Kenya	-1.350	-1.850	-1.182
Georgia	-3.371*	-2.306	-2.858	Uganda	-5.576***	-4.561**	-5.117***
Haiti	-3.825**	-3.100	-3.358*	Nicaragua	-3.339*	-3.408**	-3.652**
Kazakhstan	-1.557	-2.317	-1.776	Burundi	-3.672**	-2.643	-3.672**
Mauritania	-2.025	-4.298***	-3.129*	Botswana	-4.665***	-3.994**	-2.289
Mongolia	-4.496**	-2.965	-3.734**	Cameroon	-3.308*	-3.095	--2.815
Kyrgyzstan	-2.197	-3.021	-3.439*	International	-6.786***	-4,118**	-4.482***

Dickey fuller test. *, **, *** are 10%, 5% and 1% significance levels

Table A2. 4 Population-weighted relative price of micronutrient-dense food items by category of country

Market	Relative average monthly price growth	Relative unconditional volatility
All developing countries (n=23)	0.032**	0.013*
International market	0.009*	0.015

Relative values are calculated by subtracting the, e.g., average monthly growth in micronutrient-dense and starchy staple foods and then weighted by the population for developing country markets. *, **, *** are 10%, 5% and 1% significance levels

Table A2. 5 Conditional volatility in food prices in developing countries by food group

Country	Micronutrient-dense foods	Starchy staples	P-value	Country	Micronutrient-dense foods	Starchy staples	P-value
India	0.044	0.032	1.000	Peru	0.076	0.010	0.000
Philippians	0.019	0.018	1.000	Tunisia	0.020	0.019	0.469
Azerbaijan	0.019	0.029	1.000	South Africa	0.026	0.022	0.994
Costa Rica	0.035	0.041	0.680	Samoa	0.073	0.060	0.881
Dominican Republic	0.034	0.022	0.004	Tajikistan	0.021	0.097	1.000
El Salvador	0.075	0.047	0.001	Kenya	0.041	0.078	0.944
Georgia	0.029	0.027	0.832	Uganda	0.111	0.099	0.251
Haiti	0.026	0.051	1.000	Nicaragua	0.082	0.022	0.000
Kazakhstan	0.013	0.023	1.000	Burundi	0.110	0.085	0.117
Mauritania	0.029	0.026	0.637	Botswana	0.010	0.015	0.874
Mongolia	0.070	0.028	0.000	Cameroon	0.046	0.018	0.000
Kyrgyzstan	0.017	0.038	1.000				

The parameters presented are "garch" parameters, also known as b1 parameters in equation 4, which was our interest. We then tested the difference in the variance using F statistics.

Table A2. 6 Descriptive for the variables used in the Autoregressive regressive distributed lag panel

Variable	Upper- Middle-income countries (n=1728)	Lower-Middle-income countries (n=1713)	Low-Income countries (n=1151)	All developing countries (n=4592)	P-value
Average relative prices	1.123 (0.306)	1.058 (0.400)	1.062 (0.295)	1.083 (0.343)	0.000
Average GDP per capita PPP (dollars)	13584 (7398)	6339 (3177)	4350 (4592)	8567 (6739)	0.000
Average interest rates	15.428 (5.198)	13.871 (5.936)	18.181 (7.964)	15.537 (6.480)	0.000

The figures in the brackets are standard deviations. PPP Purchasing power parity; GDP Gross Domestic Product

Table A2. 7 Description of the data sources used in the study

Variable	Description	Source
Prices	Monthly nominal prices for several grains, animal products, fruits, and vegetables.	IMF
Prices	Monthly nominal and real prices of micronutrient-dense and starchy staple food commodities.	FAO-GIEWS
Income	Gross domestic product (GDP), purchasing power parity per capita in dollars.	World Bank
Diesel prices	Real diesel prices per litre in dollars	World Bank
Interest rates	Average bank lending interest rates (percentage)	World Bank

Chapter three

Understanding the governance challenges in scaling biofortification program in Uganda

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Abstract

As the world tries to respond to the ever-increasing food and nutrition security threats, scaling up technologies has become a priority for many research and development initiatives. Scaling up successful innovations is a value chain development process that requires efficient institutional or governance arrangements. One of those innovations that have been scaled up is biofortification in Uganda. Many institutions are involved in scaling biofortified crops, yet governance challenges are not extensively studied to provide policy direction. This study aimed to identify the governance challenges facing farmers, seed multipliers, aggregators, processors, and retailers as one of the scaling pathways and empirically test one pathway to address the governance challenge. This pathway was information provision through training. We developed a conceptual framework based on transaction cost theory to identify the causes of the governance challenges. We used the Process Net-Map to elicit information from respondents regarding processes, actors, and challenges in the food value chain of biofortified crops. The Process Net-Map involves the identification of actors, the roles the different actors play, their influence on the scaling of biofortification and challenges in the processes. The field lab experiment was used to collect data on the effect of information provision on the identification of iron beans. We analyzed the data from field lab experiments through a correlated random effects model. The results demonstrate that apart from the known agricultural marketing challenges, vine multipliers face challenges in the supply of vines, and households face a trade-off between allocating land for orange fleshed potatoes and other varieties. In addition, the value chain actors adulterate iron beans while consumers are unwilling to pay a premium price for biofortified crop products. These challenges may result from information asymmetry, merit goods, collective action, and free riding. Though information provision can improve the identification of iron beans, its effect was insignificant as from the field lab experiments. The findings show the existence of governance challenges which should be considered in planning implementation of scaling-up programs and suggest investment in subsidies to increase production while creating awareness on the importance of nutritious products.

Keywords: Information provision, biofortified crops, governance challenges, scaling

3.1 Introduction

Governance challenges in development programs can jeopardize positive development outcomes (Birner and Sekher, 2018). The current debate on why development programs have not achieved their objectives has also alluded to governance challenges (Birner et al., 2012). Bouis and Saltzman (2017) noted that governance challenges will affect achieving the target of reaching 1 billion people with biofortified crops by 2030. As such good governance is increasingly being recognized as a precondition for the effective implementation of development projects and programs (Burnside and Dollar, 2000). Literature has identified three institutions where governance challenges occur: the market, state and third sector. The challenges affecting the functioning of market and the state are market and state failure. The third sector consists of non-governmental organizations (NGOs), civil society organizations and community-based organizations (CBOs) suffer from community failure (Birner and Sekher, 2018; Illukor *et al.,* 2015; Lubungu and Birner, 2018).

Transaction theory has been used to explain the existence of governance challenges in programs. It suggests that economic agents should select the governance arrangement that minimizes the costs of economic exchange (Williamson, 1985). In other words, different governance structures would emerge in an economic exchange to minimize costs. The extensions of the theory provide the foundation for the analysis of governance challenges found in the study of fresh vegetable value chains (Eaton et al., 2008), rural service delivery (Birner and Braun, 2009), and veterinary service delivery (Ilukor et al., 2015). From these studies, three governance structures can be applied to biofortification at scale: spot markets, modular/relational and vertical integration. Spot market governance structure is where farmers sell to conventional buyers, modular is where farmers are organized in cooperatives, and relational is where farmers sell to aggregators (Kwikiriza et al., 2018).

We study the governance challenges biofortification program implementation. Our research questions are: What governance challenges can be observed in biofortified crop programs in Uganda? What are the process and influence levels of the actors in the implementation of biofortification? How are some of the governance challenges addressed? We aimed to analyze the governance challenges that are involved in program implementation and present a case on the solutions to the challenges.

Our focus is relevant to the broader literature on scaling of innovations, program planning and implementation. There is a large body of literature on governance challenges in Africa, Asia, and Latin America (Schut et al., 2020; McKeon, 2021; Behnassi and Yaya, 2011; Van Loon et al., 2020; Birner and Sekher, 2018; Lubungu and Birner, 2018). Yet most of these studies focus on livestock programs-vaccination (Lubungu and Birner, 2018), nutrition (Birner and Sekher, 2018) and innovations-mechanization (Van Loon et al., 2020; Daum and Birner, 2015). Specifically with crop varieties, Adu-Gyamfi et al. (2017) found seed adulteration in the Ghana maize seed system. There is very few evidence on governance in upper value chain-aggregation, trading and our study contributes to that scarce literature. Scaling biofortified crops has two components: nutrition education and delivery of inputs that determine the nature of governance challenges.

Secondly, awareness of biofortified crops through information provision may be linked to the reduction of governance challenges like seed quality. Yet few studies have examined farmers' information on seed quality. The few studies on farmers ' knowledge of seed quality are on maize seed. For example, a study has demonstrated that farmers who were aware of the quality of the maize seed had higher yields than those who were not informed (Hsu and Wambugu, 2022). The invisible traits in iron beans exacerbate the poor-quality seed problem in scaling biofortified crops. HarvestPlus (2018) noted that iron bean seeds have similar attributes to other bean varieties with small differences. Low quality inputs, especially fertilizers and seeds, are prevalent in developing countries, affecting farmers' productivity and income. Ashour et al. (2016) have demonstrated the impact of low-quality inputs on productivity. Theoretically, fake inputs can drive good quality inputs out of the market (Akerlof, 1970). Seed quality is important because most farmers acquire seeds by buying grain from the market or sharing grain with fellow farmers who are subject to adulteration (HarvestPlus, 2018).

The paper proceeds as follows: In section 2, we develop the conceptual framework and identify potential governance challenges based on economic theory and the literature on the food value chain. We described the methods in section 3, while section 4 presents the empirical results and discussions. Lastly, section 5 includes conclusions and policy recommendations.

Background

Understanding the governance challenges and possible solutions in scaling Uganda and globally is relevant as governments and development partners aim at reducing micronutrient deficiency. Micronutrient deficiency is a significant challenge globally, with 17% of the world population experiencing inadequate micronutrient intake (Beal et al., 2017). The number of people affected by micronutrient deficiency is expected to increase because of conflict, extreme weather, desert locusts, economic shocks, and COVID-19, which has disrupted food production and supply in recent years (Hall et al., 2021). The effects of micronutrient deficiency remain adverse and long-lasting, including pregnancy complications, child growth retardation, increased susceptibility to diseases, and impaired cognitive development (Biesalski et al., 2011). While development partners and governments have used supplementation, dietary diversification, trade policies and industrial fortification to address micronutrient deficiency, there is strong evidence that biofortification is highly effective, efficacious, and cost-effective (Murray-Kolb et al., 2017; Scott et al., 2018; Low et al., 2017). The challenge for development partners is to translate the effects of the consumption of biofortified crops into consumer demand.

Development practitioners have urged that the benefits of innovations can be realized when the innovation is scaled (Cooley and Linn, 2014). The growing interest in scaling has been because of the need to successfully transition from initial farmer adoption in pilot projects to the self-propelling and sustained uptake of technologies (Chandy et al., 2013; Cooley and Linn, 2014), and donor pressure to have an impact on many people (Glover et al., 2016). Scaling is based on the notion that meaningful impact occurs when a critical mass of societal actors embraces new work methods (Woltering et al., 2019). The early studies on scaling have concentrated on concepts, methodologies, and tools for scaling (Cooley and Linn, 2014; Rodas-Moya et al., 2022; Sartas et al., 2020). For example, Rodas-Maya et al. (2022) identified 17 indicators to track when a biofortified program is implemented at scale. These indicators range from crop variety development and delivery to enabling policy environment.

Many development organizations, research organizations and governments have implemented biofortification at scale. These organizations adopted key strategies like crowding in partners and market development as necessary demand push and pull strategies to scale up biofortification (Arimond et al., 2010). The aim is to increase the adoption, production, and consumption of biofortified crops and foods by supporting and partnering with public and private entities (Foley et al., 2021). Therefore, seed multipliers, aggregators, processors, supermarkets, and retailers play a critical role in the scaling up of biofortification. For example, supermarkets can increase farmers' income by providing markets for farmers' produce by scaling improved crop varieties (Ogutu et al., 2020).

In Uganda, with the implementation of biofortification program started in 2007 with reaching end users (REU) and later two five-year projects. These projects involved support to breeding of biofortified crops, seed production, seed delivery and value chain development. As such six iron bean varieties and 12 OFSP varieties respectively were released. It was estimated that 1,000,000 and 1,100,000 farming households were growing iron beans and OFSP by the end of 2020 (HarvestPlus, 2020). This an estimated 2 and 3.2 percent of beans and sweet potatoes produced in 2020 are biofortified, respectively. The iron beans and OFSP produced by farmers are mainly sold to consumers, retailers, processors, and aggregators at the spot markets which is the focus of this study. Some parts of the program could have been affected by governance challenges.

3.2 Governance challenges and biofortification: impact pathways

The conceptual framework showing how governance challenges can affect the scaling of biofortification is shown in figure 3.1. The impact pathway starts with breeders in the national research institutes and partners breeding and releasing biofortified crops. The crop varieties are released through the national release authorities and then licensed to seed companies, that produce certified seed for farmers to plant in developed seed systems (Arimond et al., 2010). However, in less developed seed systems and vegetative seed systems, the seed is multiplied by farmer groups or individual farmers called seed multipliers. The seed is then delivered to farmers through various actors. Once biofortified crops are harvested, households decide how to allocate the produce for consumption, sale, seed, and gift. The produce sold is made accessible to consumers by value chain actors.

This conceptual framework (Gilligan et al., 2020) does not allude to governance challenges in scaling of biofortified crops. A substantial body of empirical evidence considers governance challenges as important in implementation of programs. Although studies in mechanization, program implementation and seed systems have demonstrated governance challenges, the upper value chain like aggregation and value addition have been left out. We expand this conceptual framework to focus on the possible influence of governance challenges in the upper value chain in biofortified crops. The impact pathway could be modified by the market, state, and community failures as in the conceptual framework.

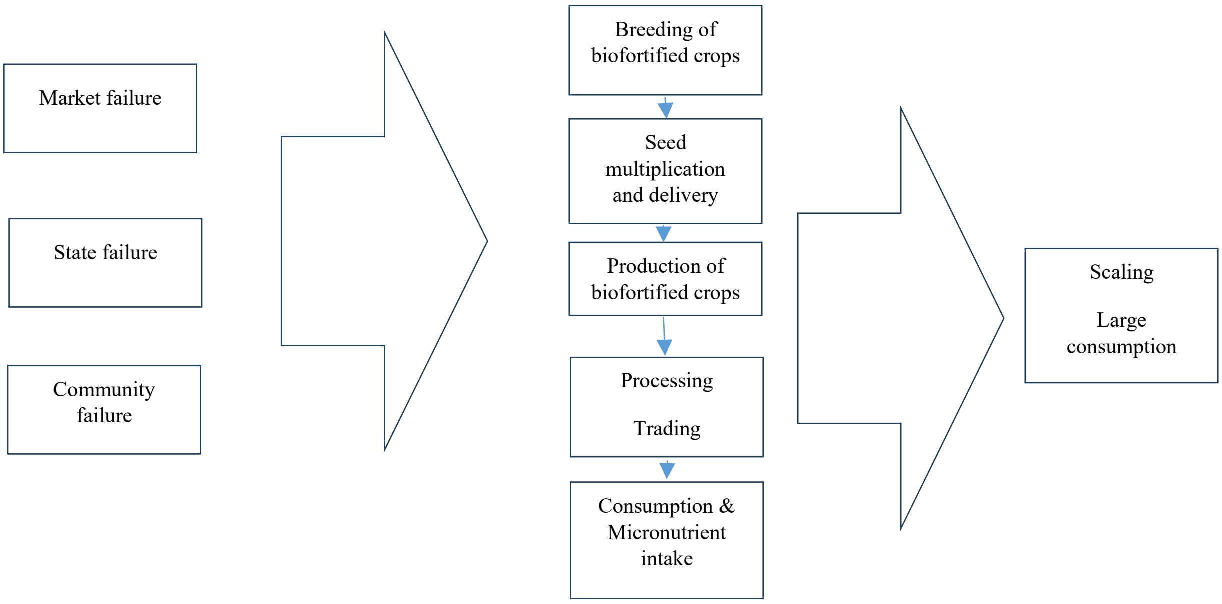


Figure. 3.1 Conceptual framework Source: Adapted from Gilligan et al., (2020)

Market failure may lead to governance challenges due to information asymmetry and nature of biofortified crops. Market failure is "the inability of a market to allocate goods or services optimal to society" (Birner and Sekher, 2018). Biofortified foods may be considered a merit good, a good that people undervalue because they don't know its future benefits. Private sectors like processors and traders do not easily emerge for these goods as there is no demand (Birner and Sekher, 2018). Biofortified crops are nutrient enriched crop varieties with higher micronutrient content than other crop varieties (Lockyer et al., 2018). Is this the case for iron bean and Orange Fleshed Sweet Potatoes crop products? The answer to this question is no because, as a merit good, consumers do not value the long-term benefits of reducing micronutrient deficiency. They may not be willing to pay a premium price. Secondly, poor consumers of biofortified crops have high time discounts. In other words, they are not willing to offer a higher premium for biofortified crop products whose benefits are in the future (Mann, 2003; Birner and Sekher, 2018). Lastly, the availability of alternative products that compete with biofortified crops affects the quantity demanded. If OFSP prices increase, consumers will shift to other sweet potatoes or readily available cassava. As a result, governments and NGOs must provide services like seeds, processing machinery, and information to reduce transaction costs. Therefore, if a system has a product characterized as a merit good, a relational and modular system with the support of NGOs and the government has a comparative advantage over spot markets.

Information asymmetry seems to be a widespread market failure for two primary reasons: first, biofortified crop products, for example, are nutrient enriched products whose demand depends on the availability of nutrition information (Birner and Sekher, 2018). Second, consumers cannot easily measure the quality of the products or verify health claims. For example, farmers cannot verify the quality of the seeds they buy, while the consumers of iron beans cannot easily verify the iron content. Governments can better address such market failure through legislation on the minimum iron level as a standard for any new varietal releases for beans, followed by strict enforcement through regular inspection. At the same time, NGOs can create awareness and build the capacity to monitor quality.

The community can organize into farmer groups along the production system to allocate goods and services when the state and market fail. However, these communities often face governance challenges because of free-riding, social exclusion, and local elite capture. The free-rider problem in collective action is because of the nature of seed for iron beans and vines, where farmers share and use saved seed, which discourages the growth of community-based seed multipliers and private-sector investment (Olson, 2009). Since the benefit of market linkage to a trader in terms of higher prices does not exclude group members, some may not contribute to the charges. As such, groups that engage in processing OFSP products like puree and flour may fail to manage the processing plant. As a result, farmers may not realize the benefits of collective action (Bizikova et al., 2020).

In perfect markets, the benefits accrue to society for the optimum allocation of goods and services. With market failure, the public sector sometimes gets involved in production systems to regulate but, most times, is limited in capacity (Feder et al., 2010). One of the underlying reasons for the governance challenges by the state is transaction intensity in agricultural programs. The involvement of many transactions and face-to-face interaction makes the transaction intense (Pritchett and Woolcock, 2004). In transaction cost economics and production economics, transaction intensity relates to transaction frequency and economies of scale, respectively (Williamson, 2005; Birner and Linacre, 2008). Low economies of scale in the food value chain may be due to the fixed cost of transporting products, which the economic agents must incur irrespective of the quantity transported. Secondly, the widely dispersed production units for agricultural produce are primarily in remote, distant rural areas (Birner and Braun, 2009; Birner and Linacre, 2008). Due to transaction intensity, governance systems like cooperatives that are close to farmers can overcome transaction intensity challenges (Sastry and Raju, 2005; Oruko and Ndung'u, 2009).

Some of the governance challenges facing the state are procurement challenges and supervision. One typical limitation in procurement is corruption. Conventionally corruption is linked to demanding bribes, stealing, misusing public resources, influence peddling and elite capture (Komakech, 2019). Bribery is Uganda's most prevalent form of corruption, costing as high as 25% of the contract sum (Komakech, 2019). The question is how corruption manifests in the scaling of biofortified crops. One possibility is through seed multipliers' involvement in sizeable public procurement to supply vines and iron bean seeds. These procurements are susceptible to bribes, influence peddling and elite capture. For example, due to bribery, the suppliers are selected not based on technical capacity (Mihály et al., 2021). The selected suppliers should have invested in production of OFSP vines, unless they supply low quality vines, which drives the actual vine multipliers out of business. The overall effect is the supply of poor-quality seeds that may lead to a phenomenon economists call the "lemon market" (Akerlof, 1970). Reducing corruption requires the government to implement the legislation and create a well enlightened community (White, 2004). With high levels of corruption, a hybrid market has a comparative advantage over the spot market.

3.3 Methods

We used qualitative and quantitative research to study Uganda's governance challenges for scaling the biofortified crops program. The qualitative method of Process Net-Map was to detail the governance challenges. We then explored the effectiveness of one of the strategies for solving the adulteration problem identified in the Process Net-Map through a quantitative approach of field lab experiments. Combining several research methods helped in understanding the problems faced in program implementation.

3.4 Process Net-Map

We used the Process Net-Map tool to identify the governance challenges in scaling the biofortified crops program. Process Net-Map records sequential processes in program implementation, highlighting potential actors and where governance challenges occur because of power or influence concentration. It allows the researcher to identify the deviations in program implementation and respondents to visualize program implementation (Schiffer and Hauck, 2010; Birner and Sekher, 2018). Process net maps have been used to identify governance challenges in large-scale nutrition programs, mechanization, cattle vaccination programs, seed systems and livestock services in Asia and Africa (Illukor et al., 2015; Birner and Sekher, 2018; Adu-Gyamfi et al., 2018; Lubungu and Birner, 2018). Implementation of the Process Net-Map followed four steps through focus group discussions or key informant interviews with respondents as indicated in Table 1. The respondents were selected based on their knowledge and involvement in the biofortification program. In the Process net map, respondents may have full or partial knowledge of the whole biofortification implementation.

We asked the respondents to describe, step by step, the process of biofortification program implementation aimed at scaling iron beans and OFSP and, at each step, identify the actors involved. The interviewer wrote the names of the actors (individuals or institutions) mentioned on a sticky note called the "actor card" and placed the sticky notes on a large sheet of paper. We draw arrows between the actors to denote the steps. We marked the arrows with numbers, as shown in Figures 2 and 3. We added consequent actors and arrows until we drew the Process Net-Map. We labelled the arrows with different colours to denote the various types of processes identified. The main links identified were the flow of information, biofortified food products, services, and capital.

In the second step, we elicited respondents' perceptions of the influence level of actors in achieving continuous production and consumption of iron beans and OFSP foods. We used checker game pieces to visualize each actor's influence level. On each actor card, participants stack each piece on top of the other so that the checker pieces form "influence towers". The height of the towers denotes the influence level assigned to an actor by the respondent. Actors considered not to influence the outcome were not given any influence towers meaning zero influence. The maximum influence level was eight checker pieces. Then, the interviewer asked respondents to explain why actors had the influence level attributed to them.

In the third and fourth steps, we asked the respondents to identify problems and with which actor the problem has occurred and suggest solutions to the challenges. It allows us to identify actor roles, linkages, or groups of links that cause governance challenges. The discussions from the Process Net-Maps were translated from the local language to English and then transcribed and analyzed with the help of MAXQDA. The four steps of the Process Net-Maps formed the categories for developing themes. We coded themes, reasons for the influence levels, governance challenges and solutions. The MAXQDA software helped analyze the discussion content to generate governance challenges and solutions. We generated descriptive statistics from influence levels. We aggregated the Process Net-Maps by drawing one general one for each crop with HarvestPlus that encompasses all the actors.

We conducted the Process Net-Map in 10 districts: Gulu, Amuru Omoro, Mbale, Kamuli, Bukedea, Serere, Ngora, Hoima and Kakumiro. The districts were selected based on the delivery footprint of HarvestPlus, which is mostly in Eastern, Western and Northern Uganda. Households in eastern region are poorest followed by northern, then western (MFEPD, 2023). HarvestPlus has worked in these districts for over ten years, promoting iron beans and OFSP production and consumption under three different projects. These projects have built the capacity of value chain actors involved in biofortification through market linkage training, radio sensitization and machinery distribution (HarvestPlus, 2018). We conducted 63 Process Net-Maps, 32 for iron beans and 31 for the OFSP, which were part of these projects (Table 3.1). We carried out individual process Net-Maps and farmer groups process net maps. On average, seven farmer group members participated in the Process Net-Maps. The respondents were purposively selected depending on their availability for the Process Net-Maps.

Table 3.1. Number of Process Net-Maps conducted

Stakeholder category	Iron beans	Orange Fleshed Sweet Potatoes
Aggregators	4	4
Retailers	6	6
Farmer groups	11	10
Processors	1	3
Seed multipliers	3	4
NGO partners	3	3
Schools	1	1
Total	32	31

Data collection took place in two phases. The first phase was between January and April 2021, while the second was in December 2021. The second data collection phase aimed to verify the results from the first data collection phase and collect additional information for the case study of aggregators. We recruited and trained six enumerators to collect data during Process Net-Map and in-depth interviews. All interviews were audio-recorded with consent from the respondent.

3.5 Field lab experiment on the identification of iron beans

Field lab experiments, also known as artefactual experiments, are increasingly being used in economics to understand farmer behavior, the effect of policies, response to shocks, subject pool differences, complement randomized controlled trials and traditional surveys (Fairbairn, 2017; Ashour *et al.* (2017 Ilukor *et al.,* 2015; Gangadharan et al., 2021). We designed a field lab experiment to assess the effect of information provision on identification of iron beans. Information was provided on the physical attributes of iron beans. Information provision is important because awareness creation through different platforms like radios and television about iron beans as one of the strategies that can increase demand and reduce adulteration of iron beans. To test the effect of this strategy, we selected groups that had grown at least one of the iron bean varieties. Two groups were selected randomly from six districts for the field lab experiment out of the list of groups. In a group, 7-8 members were purposively selected for the experiment. Farmers in these groups has grown at least one of varieties six iron bean varieties released. The agroecological region influences which varieties are grown. HarvestPlus distributed Narobean 1, 2 and 3 in the west, Narobean 2, 5 and 3 in the east and Narobean 2, 5 and 6 in the north (HarvestPlus Report, 2018). The groups participating in the field lab experiment later participated in the Process Net-Map to identify the governance challenges.

The experiment proceeded as: first, we prepared the bean samples by buying similar non-iron bean varieties in terms of physical attributes for each iron variety. A total of 22 samples, each weighing 100g, were shielded in transparent polythene. Narobeans 1, 2 and 3 had six samples in total, and Narobean 4 had four samples in total. Two similar non-biofortified iron beans were found in the market for Narobeans 1, 2 and 3, while we only found one similar non-biofortified iron bean variety for Narobeans 4. Secondly, we randomly allocated the field lab experiment participants into two categories (control and treatment). We trained the participants in the treatment group on the attributes of iron beans (grain coat colour, grain size and seed eye), similar to how farmers would get information from radios, television, extension workers or fellow farmers. We did not train control group participants. During the experiment, we displayed the samples for the farmers for identification. The four iron bean varieties used in the experiment have some distinct physical attributes that may not easily noticed by actors (Figure A3.1). Individual farmers were requested to identify iron bean varieties, and the researcher recorded the outcome as correct or false after about 1 hour of receiving the training. We repeated the identification process for the four varieties.

A total of 85 farmers participated in the field lab experiment translating 340 observations, out of which 72% were female. The high number of females is not surprising because beans and sweet potatoes are food security crops and NGOs target mainly women. Of the total number of farmers participating, 42 and 43 were randomly assigned to the control and treatment groups, respectively. A comparison of the characteristics of farmers shows that the control group differ from the treatment group in terms of the distance to the market, age of the farmer, land size, income, and asset (Table 5). Specifically, the control group farmers are older, with larger household sizes and lower land area than the treatment group. Only 46% of the participants in the control group were able to identify the iron bean correctly, while 50% of the participants in the treatment group identified the iron bean correctly.

We used a correlated random effects model to determine the effects of information provision on farmers' identification of iron beans. The model has several advantages, as it allows constant covariates within groups to be used and corrects for bias created by the correlation between unobservable covariates and treatment (Wooldridge, 2013). Jeffrey et al. (2019) used correlated random effects to determine the effects of adoption of improved chickpeas in Ethiopia. Conceptually, factors that might affect the identification of iron beans include socioeconomic characteristics, asset endowment and institutional factors. However, since the respondents are farmers who have grown at least one of the iron bean varieties, they have experience with the variety grown, biasing the training effect. We controlled for the bias caused by growing an iron bean variety by including dummy variables for regions and variety. We noted that not all four high iron bean varieties are grown in all three regions, making farmers aware of certain varieties and not others. The model is specified as follows.

$$y_{it} = \alpha + \beta x_{it} + \gamma \bar{x}_i + r_i + \mu_{it} \ldots\ldots\ldots\ldots 1$$

where y_{it} is the correct or false identification of iron beans by farmer i and variety t, x_{it} is a vector of independent variables, including training, r_i is the uncorrelated error term with x_{it} and μ_{it} is the idiosyncratic error term.

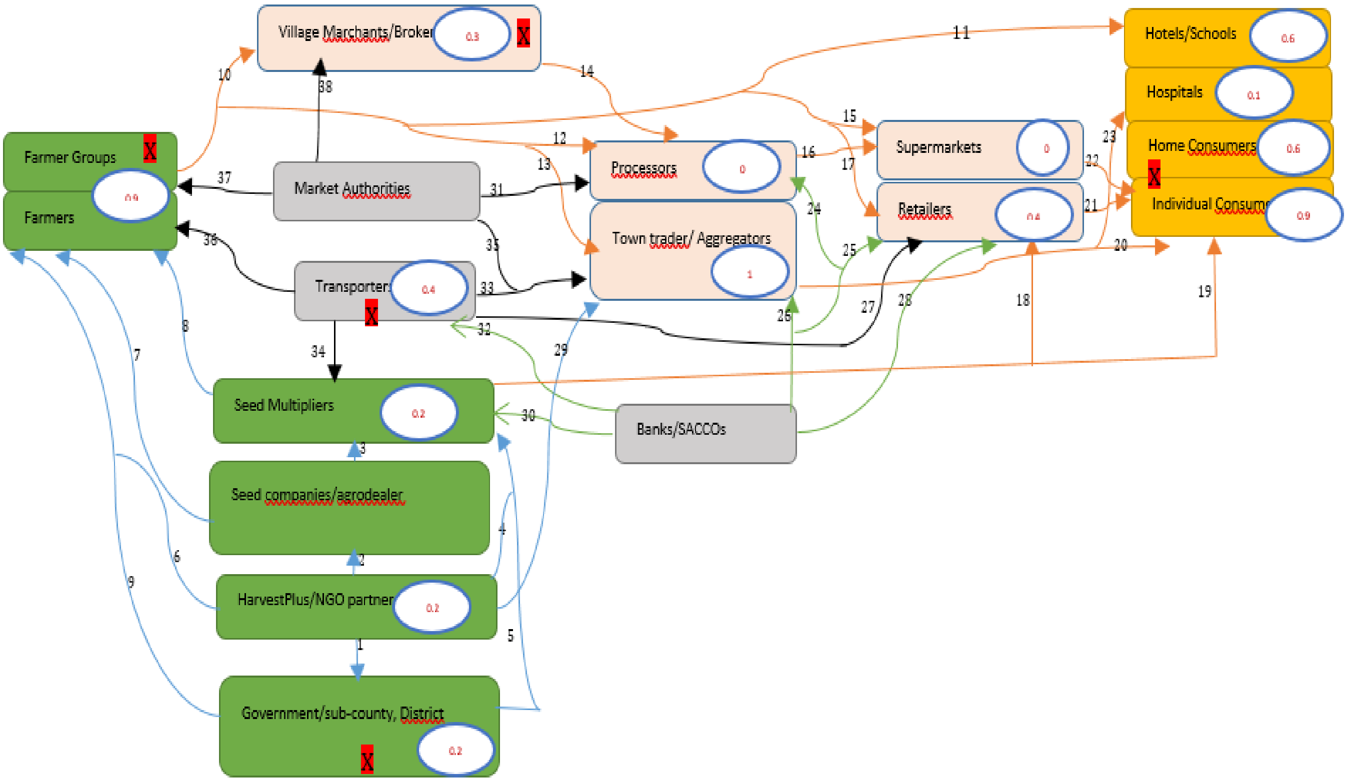
3.6 Results

This section presents the findings of the Process Net-Maps and field lab experiment. First, we show results from aggregated Process Net-Maps from different actors. Then the governance challenges in the scaling of biofortified foods are discussed. In the field lab experiment, we present the results of the effect of information provision on the correct identification of iron beans.

3.7 The Process Net-Map

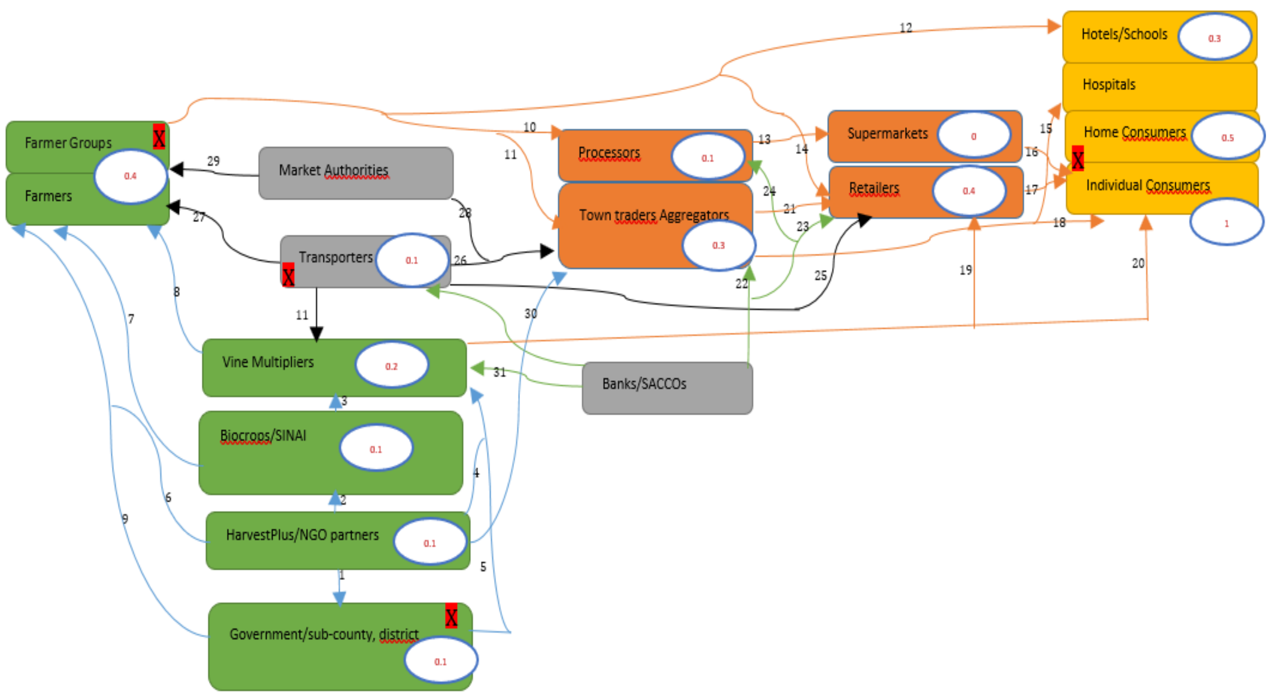
To elucidate the governance challenges in the implementation of biofortification, we started with mapping the actors. Results from the Process Net-Maps indicated that actors involved in scaling biofortified crop programs could be grouped into four major categories according to the roles, as shown in Figures 3.2 and 3.3. The first category of actors are involved in seed production, delivery, and primary production. These include National Agricultural Research Organization (NARO), International Potato Centre (CIP), HarvestPlus, partner NGOs, government, seed companies, seed multipliers, farmer groups and individual farmers. The second group of actors are involved in product development and delivery from farmers to consumers. Examples include village collectors, processors, aggregators, supermarkets, and retailers. They provide market for farmers' produce, add value, and make biofortified products available to consumers. The third group, coded grey, provides services and capital. The last group of actors are consumers ranging from individuals to institutions coded beige.

The food value chain of iron beans and OFSP starts with seed production, at least in the case of this study, because of the vital role seed multipliers play in the supply of clean planting material. Farmers make various decisions in acquiring planting material, allocation of land between biofortified crops and non-biofortified crops, land preparation, planting, and utilization of the produce. With the help of HarvestPlus and partners, farmers acquire the necessary skills for biofortified crop production through group platforms, radios, and television. The Process Net-Map discussion indicated that farmers sell their iron bean grain and OFSP roots to individual consumers, aggregators, processors, retailers, schools, and hotels (arrows 10, 11. 12, 14 for OFSP). The presence of village collectors in iron beans differentiates it from the OFSP value chain (arrows 10,11,12,13,15,17). Though the spot market governance structure, where market authorities collect fees, seems common, HarvestPlus and its partners have developed modular and relational governance systems (arrow 29 for iron beans and 30 for OFSP). In modular governance, farmers are organized in groups to add value to OFSP by processing roots into flour. Another important relationship in scaling the biofortified crops program is between aggregators and farmers. Transporters bank, village level savings and loan associations provide transportation services and capital in the food value chain.



1. HarvestPlus supports breeding, varietal release &certification of HIB	24. Financial institutions lend money to processors	Flow of OFSP roots and products
2. HarvestPlus supports multiplication of HIB seeds	25. Financial institutions lend money to retailers	Flow of capital
3. Seed company supply seed multipliers with foundation seed	26. Financial institutions lend money to aggregators	Flow of information and vines
4. HarvestPlus/NGOs train seed multipliers	27. Transportation of HIB grain for retailers	Flow of services
5. Government certifies seed from multipliers	28. Financial institutions lend money to retailers	Perceived influence level
6. NGOs/HarvestPlus distribute HIB seed and train farmer groups	29. HarvestPlus/NGO partners train and provides market linkage to aggregators	X Governance challenges
7. Seed companies/agrodealers sell HIB seed to farmers	30. Financial institutions lend money to seed multipliers	
8. Seed multipliers sell HIB to farmers/farmer groups	31. Market authorities collects fees from processors	
9. Government under different programs distribute HIB seed to farmers	32. Financial institutions lend money to seed transporters.	
10. HIB grain is sold to middlemen by farmers/groups	33. Transportation of HIB grain for aggregators	
11. Farmers sell HIB grain to consumers-hotels, individuals etc	34. Transportation of HIB seed for seed multipliers	
12. Iron beans is sold to processors by farmer groups/farmers	35. Produce fees is collected from aggregators	
13. Farmers sell HIB grain directly to aggregators in their stores	36. Transports HIB grain for farmers	
14. Village collectors sell HIB grain to processors and aggregators	37. Market authorities collects fees from farmers in spot markets	
15. Farmers supply supermarkets with HIB grain	38. Market authorities collects fees from middlemen	
16. Processors supply supermarkets with processed products of HIB		
17. Farmers sell to retailers HIB grain		
18. Seed multipliers sell grain to retailers		
19. Seed multipliers sell HIB grain to individual consumers		
20. Aggregators sell HIB grain to consumers-Individuals, schools, etc		
21. Retailers sell HIB grain to retailers in spot markets		
22. HIB grain is sold to individual consumers by supermarkets		
23. Aggregators supply institutions like schools		

Figure 3.2: Network of Actors involved in the value chain of Iron beans



1. HarvestPlus supports breeding, varietal release &certification of OFSP	20. Vine multipliers sell OFSP roots to individual consumers	Flow of OFSP roots and products
2. HarvestPlus supports cleaning and multiplication of OFSP vines	21. Supplies OFSP roots to retailers	
3. Biocrop/Sinai supply vine multipliers with vines	22. Financial institutions lend money to aggregators	Flow of capital
4. HarvestPlus/NGOs trains, supply screen house materials & buys vines		
5. Government certifies vine multipliers	23. Financial institutions lend money to retailers	Flow of information and vines
6. NGOs/HarvestPlus distribute vines and trains farmer groups	24. Financial institutions lend money to processors	
7. Sinai/Biocrops collects field vines for cleaning		
8. Vine multipliers supply vines to farmer/farmer groups	25. Transports OFSP roots for retailers	Flow of services
9. Government under different programs supplies vines to farmers	26. Transportation of OFSP roots for aggregators	
10. Farmers/groups sell OFSP roots to processors		
11. Farmers/groups sell OFSP roots to aggregators	27. Transports farmers OFSP roots	Perceived influence level
12. Farmers/groups sell OFSP roots to hotels	28. Produce fees is collected from aggregators	
13. Processors sell OFSP products to supermarkets	29. Market authorities collects fees from farmers in spot markets	Governance challenges
14. Supplies OFSP products to retailers by farmers		
15. Aggregators sell OFSP roots to institutions-schools, hotels		
16. Supermarkets sell OFSP products to individual consumers	30. HarvestPlus/NGO partners train and provides market linkage to aggregators	
17. Sells OFSP roots to consumers - individuals by retailers		
18. Sells OFSP roots to consumers - individuals by aggregators	31. Financial institutions lend money to vine multipliers	
19. Vine multipliers sell OFSP roots to retailers		

Figure 3.3: Network of Actors involved in the value chain of OFSP

Comparing the Process Net-Maps for the OFSP and iron beans revealed that respondents had identified similar types of actors and their roles. Similar studies on governance challenges have shown convergence of participants on the roles of actors and governance challenges but differed on the perceived influence levels (Birner and Sekher, 2010; Ilukor et al., 2015; Adu-Gyamfi et al., 2017). The variation in the number of actors, roles of actors and governance challenges between iron beans and the OFSP program implementation may be due to the nature of the crop. One key difference is that OFSP roots are perishable, while iron beans can be stored for long period. Secondly, the results showed that the OFSP processors are in the rural study districts under the modular governance system, while the iron beans processing plant is in Kampala, the capital city. The extent and role of supermarkets and institutional buyers like schools and aggregators were similar in iron beans and OFSP. However, few supermarkets are yet involved in selling iron beans and OFSP food products.

3.8 Influence levels of the actors

Influence level suggests the importance of actors and in most cases where the governance challenges would happen in the program implementation. Table 3.2 presents the results for the actor's perceived importance rating by respondents. We calculated the mean influence level and the range as the difference between the lowest and highest rate. We found some actors mentioned in a few with high rates in Process Net-Maps biasing the mean influence rate. We weighted the mean with the proportion of the number of times an actor appeared in the Process Net-Map discussions. An actor mentioned a few times indicates fewer interactions in the scaling of the biofortified crop program. The weighted influence rate was normalized, where one means the highest rate and zero is the lowest. Respondents in both OFSP and Iron Beans agreed that consumers (individual consumers, schools, home consumers, and hotels) are the most influential actors because they provide market for the products. One of the major consumers of iron beans and OFSP food products is household members rated 0.6 and 0.5 for iron beans and OFSP, respectively. Similarly, studies on biofortified crops have shown that most household production is for own consumption (HarvestPlus, 2018). Schools provide an exciting set of consumers because a) micronutrients are supplied directly to the children who are most affected by micronutrient deficiency and b) farmer market linkage through education institutions where biofortified foods are sold to schools by farmers to facilitate school fee payment.

Supermarkets are the least important according to the results. This finding correlates to respondents not perceiving processors as influential since they supply supermarkets. The few processed products may explain the low influence of supermarkets as they sell mainly processed products in urban areas. Contrarily, quantitative studies have demonstrated the importance of supermarket contracts for vegetable farmers in Kenya (Ogutu *et al.,* 2020). One of the actors that HarvestPlus and partners have been promoting to drive the scaling of iron beans and OFSP are the aggregators. Although participants in the iron beans value chain perceive aggregators as highly influential (influence level one), that is not the case with the OFSP value chain (influence level, 0.3). The nature of the products, especially perishability and the role of storage, may explain the difference in the influence rates. Aggregators are perceived to have capital used to buy large volumes of stock. Secondly, aggregators may improve product quality through sorting and branding.

According to the results, actors involved in the seed systems are less influential in the food value chain of both iron beans and OFSP. These actors include the National Agricultural Research Organization (NARO), seed companies, agro-dealers, vine multipliers, the International Potato Centre (CIP), integrated seed system development (ISSD), Sinai, Biocrops and HarvestPlus. These "supply-side" actors are involved in breeding, cleaning vines, multiplication, and delivering planting material for biofortified crops. Although HarvestPlus and partners (influence level 0.1) are involved in awareness creation on the nutritional value of biofortified crops and other scaling activities, it does not translate for the participant to perceive them as influential.

Table 3.2: Perceived influence levels of different actors in the biofortified food value chain

Actor	Iron bean				Orange sweet potatoes			
	Mean	Min	Max	Range	Mean	Min	Max	Range
Individual consumers	0.94	3.00	8.00	5.00	1.00	3.00	8.00	5.00
Household consumers	0.63	8.00	8.00	0.00	0.48	6.00	8.00	2.00
Hospitals					0.08	5.00	7.00	2.00
Hotels	0.57	5.00	8.00	3.00	0.30	1.00	6.00	5.00
Schools	0.61	2.00	8.00	6.00	0.43	4.00	8.00	4.00
Transporters	0.40	3.00	8.00	5.00	0.02	4.00	4.00	0.00
SACCO/Banks	0.11	2.00	6.00	4.00	0.02	1.00	6.00	5.00
Supermarkets	0.01	1.00	5.00	4.00	0.01	0.01	0.00	0.00
Aggregators	1.00	2.00	8.00	6.00	0.30	5.00	6.00	1.00
Regional Market traders	0.20	5.00	5.00	0.00	0.16	8.00	8.00	0.00
Small scale retailers	0.53	3.00	8.00	5.00	0.35	3.00	7.00	4.00
Processors	0.01	0.00	0.00	0.00	0.15	6.00	6.00	0.00
Village Merchants/brokers	0.26	3.00	7.00	4.00				
Farmer Groups	0.29	7.00	8.00	1.00	0.17	2.50	8.00	5.50
Seed company/Vine multipliers					0.14	6.00	8.00	2.00
HarvestPlus	0.20	6.00	8.00	2.00	0.11	7.00	8.00	1.00
National Agricultural Research Organization	0.11	8.00	8.00	0.00	0.10	6.00	8.00	2.00
NGO partners (VEDCO/WV/HOCADEO)	0.10	6.00	8.00	2.00	0.10	4.00	8.00	4.00
Fellow farmers	0.85	2.00	8.00	6.00	0.64	2.00	8.00	6.00
Integrated Seed System Development	0.07	5.00	6.00	1.00				
Biocrops/Sinai					0.07	6.00	8.00	2.00
International Potato Centre (CIP)					0.11	7.00	8.00	1.00
Governments at subcounty	0.01	1.00	5.00	4.00	0.10	4.00	8.00	4.00

Source: Own calculations based on process net map: The mean presented in the table is normalized by subtracting the mean from each actor from the grand mean and dividing it by the standard deviation. SACCO is a savings and loan association, VEDCO, WV and HOCADEO were local NGOs implementing scaling program.

3.9 Governance challenges in the scaling of biofortified crops

In section 2 of this paper, the conceptual framework has shown various factors that may result in governance challenges in the scaling of biofortified crops. Using field study, we present empirical results on governance challenges in Table 3.3 based on content analysis during the process net maps. We limit the governance challenges to vine multipliers, farmers, aggregators, processors, and retailers, as shown in Figures 3.2 and 3.3, to stay within the study focus.

Table 3.3: Problems in biofortification program implementation

Problem description	Mention (n=63)
Household unwillingness to allocate land for biofortified crops	6
Problems in the supply of OFSP vines by multipliers	22
Maintaining the good quality of biofortified products	8
Unwillingness to pay a premium price for biofortified crop products	28
Problems in the modular governance system	13
Lack of access to finance	9

Source: Own calculation based on process net map

Household unwillingness to allocate land for biofortified crops.

Land allocation is a governance challenge in the household that affects biofortified crops' production mentioned six times in the content analysis. Men in some households are less willing to allocate more land to produce OFSP. The land allocation problem is more prevalent in western Uganda than in other parts due to the low comparative advantage of OFSP over bananas. Bashaasha and Mwanga (1992) showed that the comparative advantage of sweet potatoes was lower than that of bananas. In addition, the land is a binding constraint of production in western Uganda. Households would prefer allocating more land to bananas, which have more comparative advantage than sweet potatoes. The low area allocated for OFSP translates into a low percent area under biofortified crops, one of the critical indicators of biofortification implementation at scale (Rodas-Moya et al., 2022). Interventions like market linkage, value addition through processing and awareness creation by NGOs and the government would increase area allocation for biofortified crops.

Problems in the supply of OFSP vines by multipliers

The problem in the supply of vines had 22 mentions in the process net map. The governance challenge mentioned was corruption in the procurement of vines. Government and NGO procurements of vines are the most reliable for vine multipliers because of large quantities procured at premium prices. Respondents noted that governments and NGOs procure on average 500 bags of vines at 40,000 Ugandan shillings compared with a bag at 5,000 Ugandan shillings by individual farmers. Farmer have less incentive to buy vines because of freeriding where farmer saved and sharing of vines that is common (HarvestPlus, 2018). Government and NGO procurements of OFSP vines are motivated by the economic benefits of the projects in terms of micronutrient deficiency reduction. The large quantities of vine procurements are prom to corruption by district or subcounty technical people. By design, the vine multiplier applies for a contract to supply, with the application going through a contracting process. One participant stated that *"technical people in the district charged with ensuring the quality of planting material delay verification of our supplies so that we can pay kickbacks "*. The power to demand a kickback payment is derived from the recipient's authority to provide a signature required in the release of funds process. Birner and Sekher (2018) identified actors who sign for funds in government offices to be involved in corruption.

Maintaining the good quality of biofortified products

The quality governance challenge in scaling biofortified crops is due to the trader behaviour and the product's nature. First, farmers' late harvesting of OFSP reduces the self-life in storage as the roots are perishable. Secondly, adulterating beans with other varieties has been a problem in the bean sector while bulking for a long time (CASA, 2020). Value chain actors adulterate iron bean varieties with other bean varieties. The results revealed that beans are adulterated mainly by village merchants, retailers, and to a limited extent, farmers that are perceived as important. Adulteration is prevalent in the bean sector for the following reason. The iron trait in the bean is invisible. Consumers cannot easily differentiate between iron bean and non-iron bean varieties in the market, and even producers of iron beans have difficulty identifying their products. For instance, Narobean 3, one of the iron bean varieties, is yellow and has a similar grain size to other yellow bean varieties. Secondly, the actors' profit maximization behavior may drive mixing since desegregation involves sorting costs.

With such market failure, the government typically legislates to reduce the market failure and then monitors the quality of products in the country. The mandate to monitor the quality of products, in general, is concentrated on Uganda bureau standards with limited staff. East Africa has an old bean standard that is not enforced, as aggregators and brokers typically do not buy beans based on those quality parameters (East Africa, 1919). Traders purchase beans based on visual criteria such as variety, colour, size, moisture content, insect damage, and foreign matter. There are no incentives for traders and processors to adopt the bean standard. Community based organizations and NGOs may train consumers about the nutritional importance of OFSP and iron beans so that consumers would be willing to pay a premium price that can cover the transaction costs incurred by traders. They could strengthen relational and modular governance systems to reduce costs in the supply chain of iron beans and OFSP products.

Unwillingness to pay a premium price for biofortified crop products.

The results indicated that consumers might be less willing to pay a premium price for OFSP roots and iron beans and yet they are considered important. One retailer stated that *"we mix the OFSP with yellow sweet potatoes so that we can be able to sell them as my customers pay the same price for both yellow and orange"*. Several possible reasons could explain this market failure. First, in section 2.0, we noted that biofortified crop products are characterized as merit goods whose long-term nutritional benefits are not valued, especially by poor households with high-time discounts. Secondly, in many cases, consumers are unaware of the health benefits of biofortified crops. Quantitative studies based on both stated and revealed preferences seem to agree that consumers are willing to pay a premium for biofortified crop products (Oparinde *et al.,* 2016; Bocher *et al.,* 2019; Ongudi *et al.,* 2017). For instance, Ongudi *et al.* (2017) used a contingent valuation method to estimate consumer willingness to pay for pearl millet in Kenya. The findings indicated that consumers would pay an average premium of 42% above the prevailing market price of finger millet varieties. Another study on yellow cassava in Nigeria found that consumers are willing to pay a premium price for the yellow cassava variety (Oparinde *et al.,* 2016). All these studies focus on consumers who largely determine the pricing decisions of value chain actors (Breidert *et al.,* 2006). These studies and our study agree on the role of information about nutritional value in improving consumers' willingness to pay. Information on the nutritional value of biofortified crops would allow the market forces of demand and supply to allocate prices optimally.

Problems in the modular governance system

The results indicated that poor machinery management and a low supply of OFSP roots were central problems in modular governance systems. Poor processing machinery maintenance is a classic collective action problem, principle-agent problem, elite capture, and lack of machine operators (Daum and Birner, 2017). The results indicated that unknown people damaged the solar drying equipment. However, due to the free rider problem, where individual members use the drying services for their OFSP roots without contributing to its maintenance or security. Another challenge with maintenance was the principal-agent problem, where the machine operators are the agents, and the farmer group members are the principals. The machine operators are generally not supervised by the farmers and have few incentives to ensure proper maintenance because they may not bear the costs of breakdowns. In addition, it is difficult to find well-trained people to carry out the maintenance of machinery.

Even when farmers form cooperatives, they cannot amass large enough OFSP roots to achieve the processing machinery's total operational capacity and meet the required quantities by aggregators or retailers. The results showed that the supply of iron bean grain and OFSP roots was low, even if aggregators and retailers wanted to buy larger quantities. When the processing machinery operates at a suboptimal level, marginal costs will be greater than the price (Varian, 2014). Farmers face several production constraints, including access to quality seed, land constraints, and weather risks. These numerous constraints prevent farmers from producing larger volumes of surplus biofortified crops for sale.

The results revealed that aggregators for both iron beans and OFSP had employed the following strategies: a) subsidies on seeds, b) building trust with farmers and c) investing in storage to increase the self-life of iron beans and OFSP roots bought. One of the aggregators said, *"I give some farmers iron bean seed that I obtain from seed companies on credit and then buy the grain from the farmers after harvest"*. Supporting farmers with seed subsidies were common with Iron bean aggregators. The aggregators would give farmers quality iron bean seed and, at the harvest, buy grain from the farmers. The informal contracts ensure the per unit costs are reduced due to large quantities of transactions. HarvestPlus reports have indicated that 20% of the aggregators have informal agreements with farmers (HarvestPlus, 2020). Studies by Arouna and Michler (2019); Barrett *et al.* (2019); Bellemare (2018) suggests that aggregators could benefit from formal contracts with farmers through reduction of transportation costs.

Lack of access to finance

The governance challenge credit was prevalent in both OFSP and iron beans value chain actors. Aggregators, retailers, and processors of biofortified crops require credit to increase their working capital, facilitating purchases, storage, and acquisition of machinery. The results showed that challenges in accessing credit might be due to the following reasons. First, applying for a loan from a private bank is tedious, and the repayment schedule is stringent and not adapted to the agri-food sector. For example, value chain actors must pay loans continuously within 12 (rarely 24) months. Secondly, the banks' interest rates are high, on average 20% per year, because of transaction costs, inflation, and default rates (Oketch, 2022). Thirdly, aggregators, retailers, and processors' lack of collateral discourages banks from lending money.

3.10 Outcomes from the field lab experiments

The field lab experiment, a growing methodology in experimental economics extends the governance challenges component of the study to test the effect of training. Iron beans was selected because of invisible trait making it susceptible to adulteration. Among iron bean growing households, we estimated the effect of information provision farmers on the physical attributes of iron beans using the correlated random-effects model. The variation across iron bean varieties was assumed to be random and correlated with regressors biasing estimates. Table 3.4 shows the results from the model where the dependent variable was correct or false identification while the independent variable was training on physical attributes. We also present estimates from a probit model next to correlated random effects models for comparison. Though coefficient estimates for the different independent variables from the two models have the same sign, their magnitudes are different, with higher estimates from the probit model suggesting positive selection bias.

The correlated random effect model results indicated that training on physical attributes does not significantly affect the probability of correctly identifying iron beans. The results confirm the difficulty in identifying iron bean grain from section 3.2, though there are slight differences in the bean varieties. The descriptive analysis indicates that 46% and 50% of the farmers in the control and treatment groups correctly identified the iron bean varieties, respectively. A similar result of farmers' failure to differentiate iron beans from similar varieties was highlighted by Omari et al. (2019). Consumers that may have heard about iron beans without prior experience may have a higher chance of misidentification, leading to a suboptimal iron intake. Institutional factors and farmers' location were important in determining farmers' likelihood of identifying iron beans. Farmers with access to the extension services were less likely to identify iron beans. One reason could be that farmers may have forgotten the physical attributes of iron beans, or the training might have focused on agronomy, marketing, and nutrition. Farmers with access to credit were more likely to identify the iron beans, while those distant from agrodealers were less likely to identify them correctly. Farmers in western and eastern regions are more likely to identify iron beans, as HarvestPlus distributed more varieties.

Table 3.4: Correlated random effects model for the effect of training on the identification of iron beans

Variable	The correlated random effects model	Probit model
Training (1=Yes)	0.092	0.261
	(0.073)	(0.209)
Narobean 1 (1= Narobean 1)	0.071	0.207
	(0.085)	(0.246)
Narobean 2 (1= Narobean 2)	0.018	0.052
	(0.085)	(0.243)
Narobean 3 (1= Narobean 3)	0.179**	0.526**
	(0.085)	(0.254)
Age of farmer (years)	-0.003	-0.009
	(0.003)	(0.009)
Household size	-0.011	-0.034
	(0.011)	(0.032)
Sex of the farmer (1=Female)	-0.048	-0.151
	(0.072)	(0.215)
Education of the farmer (1=primary, 0=otherwise)	0.022	0.024
	(0.135)	(0.395)
Education of the farmer (1=secondary, 0=otherwise)	0.149	0.466
	(0.149)	(0.431)
Total livestock units	-0.012	-0.042
	(0.021)	(0.062)
Extension service (1=Yes)	-0.173*	-0.494*
	(0.088)	(0.260)
Credit (1=Yes)	0.185*	0.602*
	(0.105)	(0.311)
Log Income	-0.037	-0.119
	(0.056)	(0.155)
Land (ha)	0.013	0.061
	(0.029)	(0.089)
Distance to the nearest agrodealer (Km)	0.095***	0.287**
	(0.045)	(0.139)
Distance to the nearest output market (Km)	-0.027	-0.069
	(0.043)	(0.132)
Distance to a nearest all-weather road (Km)	-0.047	-0.149
	(0.052)	(0.154)
Location-Kamuli	0.227*	0.690*
	(0.127)	(0.386)
Location-Kakumiro	0.366***	1.121**
	(0.101)	(0.307)
Constant	0.927	1.329
	(0.822)	(2.269)
N	340	340
Wald chi2	-137	37.23
	(0.000)	(0.000)
R-squared		0.1501

Source: Own calculation. The figures in the brackets are the standard errors, and *, **, *** are 10%, 5%, and 1% significance levels, and N is the number of respondents.

3.11 Conclusion and policy recommendations

This study examined the governance challenges in scaling up the biofortification program in Uganda and tests the effect of information provision on identifying iron beans. The governance challenges are complex because they involve several government, market, and community actors. One of the challenges was corruption in the supply of OFSP vines by the government actors. Since vine multiplication is asset-specific due to investments in training, screen house and irrigation, challenges in vine supply may lead to low-quality vines in the seed market. Another challenge was unwillingness to pay premium price by consumers. As a result of information asymmetry, consumers were less willing to pay a premium price for biofortified crop products. Aggregators and other actors for iron beans adulterate the iron bean grain with other bean grains. The farmer groups formed to reduce transaction costs in modular governance systems also have several governance challenges, for example, poor management of machines due to elite capture by the leaders and freeriding by some members. The field lab experiments suggest that information provided through training on physical attributes may not significantly improve the ability of farmers to distinguish between iron beans and non-iron beans. Addressing the governance challenges would enable effective scaling of biofortification in Uganda and globally.

This paper proposes three strategies to reduce the governance challenges. As assessed by our study there is corruption in supply of vines. In that regard, legislation on seed system that address the quality of planting material in the country is important. The legislation would allow for certification of sources of planting materials. Government and NGO procurements would come from certified sources where quality is monitored. Ministry of Agriculture conducts certification of vine multipliers (HarvestPlus, 2018). In addition, enforcement of the legislation is important as it ensures compliance with the legislation. Secondly, we established that value chain actors adulterate iron beans because of invisible traits and mix OFSP with other varieties. Subsidies on iron bean and OFSP planting material through government and NGO programs may be viable for addressing this governance challenge. This is because subsidies would increase production of iron beans and OFSP saturating the market (Sibande et al., 2017). At optimal supply of iron beans and OFSP in the market, the consumers have a high probability of buying iron beans and OFSP.

Lastly, we would like to draw attention to some shortcomings of the current work. Our in-depth assessment of governance challenges of iron beans and OFSP covers two crops with different seed systems which could still be biased. This is because in Uganda the seed system and value chains are not yet developed which might result in state and market failures. Scaling innovation like biofortification involves public sector governance, leadership and management, collaboration, and evidence learning in seed system and policy which were not assessed in our case study. Yet, these segments are important in large scale adoption and consumption of biofortified crops to improve rural livelihoods. A small sample size in the field lab experiment could also have weakened the statistical reliability and representativeness of the results. The participant of the field lab experiment are groups that had planted iron beans biasing the results. Results of the field lab experiment are presented in this paper for preliminary testing of the hypothesis, as well as for demonstrating the methodological toolbox. Further study on the scaling of biofortification could entail using the scaling readiness scan. Secondly, our study focused on governance challenges in the food system. Future studies need to focus on the governance systems in the seed systems that have not been explored and is important for scaling. Thirdly, the study provided insight into the effect of information provision on identifying iron beans using the field in a lab experiment. The experiment was constrained by time. The experiment would be improved by including more treatments like training with picture samples and videos (Hörner et al., 2019). This could be done in random control experiments or analysis involving quasi-experimental methods to complement the result of field lab experiments.

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A3: Appendix for chapter three

Table A3. 1 Descriptive statistics of farmers participating in the field lab experiment

Variable	Treatment (n=43)	Control (n=42)	Difference
Identification (% of correct identification of iron beans)	50	46	
Household size	8.00	6.64	1.54**
Age of farmer (years)	44.21	36.93	7.28***
Distance to the nearest output market (Km)	2.39	2.36	0.03
Distance to the nearest agrodealer (Km)	2.43	2.46	0.04
Sex of the farmer (1=female, 0=otherwise)	0.64	0.53	0.11
Land (ha)	1.39	1.89	0.50*
Log Income	14.61	14.85	0.25
Credit (1=received credit, 0=otherwise)	0.28	0.18	0.11
Extension service (1=extension, 0=otherwise)	0.46	0.39	0.07
Total livestock units	1.78	1.21	0.57

Figure A3. 1 Newly released iron beans in Uganda

NEWLY RELEASED BIOFORTIFIED BEAN VARIETIES.

NAROBEAN 1

• **Type:**	Bush
• **Seed size:**	Medium seeded
• **Iron:**	65.8 - 72 ppm
• **Zinc:**	31.4 - 34.2 ppm
• **Yield potential:**	1500 - 2000 kg/ha
Maturity:	60 - 68 days
• **Best suited for:**	Low-mid altitude area

NAROBEAN 2

• **Type:**	Bush
• **Seed size:**	Medium seeded
• **Iron:**	66.1 -72 ppm
• **Zinc:**	32.5 - 36.2 ppm
• **Yield potential:**	1600 - 2200 kg/ha
Maturity:	58 - 68 days
• **Best suited for:**	Low-mid altitude area

NAROBEAN 3

• **Type:**	Bush
• **Seed size:**	Medium seeded
• **Iron:**	65.4 - 69 ppm
• **Zinc:**	35 - 38 ppm
• **Yield potential:**	1500 - 2000 kg/ha
Maturity:	58 - 68 days
• **Best suited for:**	Low-mid altitude area

NAROBEAN 4C

• **Type:**	Climber
• **Seed size:**	Large seeded
• **Iron:**	77.4 - 83 ppm
• **Zinc:**	32.1 ppm
• **Yield potential:**	2500 - 3700 kg/ha
Maturity:	82 - 88 days
• **Best suited for:**	Mid-high altitude area

NAROBEAN 5C

• **Type:**	Climber
• **Seed size:**	Large seeded
• **Iron:**	72.2 - 80 ppm
• **Zinc:**	34.7 ppm
• **Yield potential:**	2500 - 3700 kg/ha
Maturity:	88 - 96 days
• **Best suited for:**	Mid-high altitude area

Chapter four

Distribution, contracts, and performance: a case of aggregators, processors, and retailers in vitamin A cassava food chain in Nigeria

This chapter has been submitted for publication as Alioma, R. Zeller, M. Bahru, B. A., (2023). Distribution and performance of aggregators, processors, and retailers in vitamin A cassava food chain in Nigeria Food Policy (FOODPOLICY-D-23-00224)

Abstract

Recently, there has been a growing focus on the involvement of aggregators, processors, and retailers in developing value chains for staple food crops. The interest in value chain actors is because of the importance of value chain development in improving farmers' welfare. This paper provides evidence on factors determining the distribution and performance of aggregators, retailers, and processors in Nigeria's vitamin A food value chain. We have used unique data sets from several sources. First, we used annual data collected by HarvestPlus for vitamin A cassava and Vitamin A maize value chains to assess the outcome indicators. Secondly, we generate values of variables used in determining the distribution of value chain actors from living standard measurement study data in local government areas. Using local government areas and georeferenced data, we analysed the data using the spatial distributed lag model to determine factors that affect the distribution of aggregators, retailers, and processors. We also used the correlated random effects model to assess the role of contracts on their performance. We found that the location of aggregators, retailers and processors seem not be associated with infrastructural and supply variables. Out of the demand variables, ownership of livestock and the price of *Garri*-cassava flour influenced the location of retailers and processors. Contracts seem to reduce the cost per kilogram for aggregators and retailers while insufficiently affecting the costs of processors. We recommend more investigation into the association between contracts and the performance of aggregators, processors, and retailers.

Keywords: Contracts, Value chain actors, Price margin, Unit costs

4.0 Introduction

Distribution and contracts in the food system are important in developing staple crop value chains through placement of programs, and reduction of transaction costs leading to improvement in farmer's welfare (Zeller et al., 2002; Liverpool-Tasie et al., 2020). Literature shows that the distribution of economic entities is a reflection of targeting by government and development partners with objective of poverty reduction. Zeller et al. (2002) showed that the placement of saving and loan groups in Bangladesh followed poverty consideration in addition to reduction of transaction costs. Secondly, contracts with farmers guarantee production quantities by reducing the risk faced by value chain actors. The large literature on contracts is skewed towards the benefit accrued to farmers through access to inputs, technologies, and markets, impacting positively on productivity and welfare outcomes (Maertens and Velde, 2017; Soullier and Moustier, 2018). Maertens and Velde (2017), for example, have shown that contract farming for staple food crops can be sustainable and beneficial to smallholder farmers.

We contribute to the literature on value chain performance by extending work on placement (Zeller et al. 2002; Wollni and Camilla, 2013; Schmidtner et al., 2012) and contracts (Soullier and Moustier, 2018), where we analyze the determinants of location and effect of contracts on performance of aggregators, processors, and retailers. The placement of value chain actors is rooted in economic geography (Fujita et al., 1999), poverty, demand and supply factors (Zeller et al., 2002). Few empirical studies have tried to test theoretical predictions of economic geography in agricultural value chains and the effect of contracts on performance of value chain actors. We test the hypothesis that placement of the value chain actor (VCA) in Local Government Areas in Nigeria are correlated and follows local administrative areas with high poverty and micronutrient deficiency (LGA[8]). At the same time, the theory of the firm suggests that VCA maximize profits under contract conditions. The empirical evidence has been limited on the importance of contracts for VCAs. We have two objectives in this paper. The first is to determine the factors that affect the placement of aggregators, processors, and retailers. The second objective examined the effects of contracts on the cost per unit and price margin of value chain actors. We hypothesize that contracts negatively correlate with unit costs and price margin.

[8] Nigeria has 774 local government areas (LGAs), each administered by a local government council consisting of a chairman, who is the chief executive, and other elected members, who are referred to as councillors. Each LGA is further subdivided into a minimum of ten and a maximum of twenty wards.

Our focus is important for the broader literature of targeting and contracts that enhance scaling of innovations. On placement, there is a large body of empirical literature on factors that determine the placement of programs by NGOs and governments. These studies have found that poverty, cost of operation and sometimes political patronage influence placement (Zeller et al., 2002; Brass, 2012; Asero-Marfo et al., 2013; Dipendra, 2019). Yet most of these studies focus on programs that are donor or government driven. However, scanty information is available on the placement of aggregators, retailers, and processors in the staple food value chain, whose placement may be explained by the standard cost of production theory (Varian, 2014) where firms are located where the projected marginal costs are less than the price.

The empirical evidence on the participation of value chain actors in contracting with farmers is dominated by the benefits of productivity and welfare implications of this participation globally (Randrianarison and Swinnen, 2009; Rao, Bruemmer and Qaim, 2012, Cahyadi and Waibel, 2013; Barrett et al., 2012). Most of these production or marketing contracts are between one large value chain actor, for example, a processor, supermarket, and farmers. The crops targeted are high value products (mostly fruits and vegetables and products) and industrial commodities (mostly palm oil, coffee, cocoa, rubber, and cotton) destined for export, and large scaling processing (Bolwig et al., 2009; Cahyadi & Waibel, 2013). There is little evidence on the benefits of contract for aggregator, processors and retailers in staple and domestic food chains, and the objective of this study contributes to this scarce evidence.

Understanding the implication of placement and contracts of aggregators, processors and retailers in vitamin A cassava is relevant because of scaling and policy reasons. HarvestPlus, governments and development partners aim to reduce micronutrient deficiency through scaling biofortification. HarvestPlus (2021) dispels the roles each stakeholder would play to achieve scaling of biofortification. Foley et al. (2021) have reported that several countries are including biofortification in their policies. The policies pave the way for program implementation and more research to inform the evaluation of the policy. First, Nigeria is implementing scaling climate and nutrition innovative crops through market systems among programs to scale interventions. In the global nutrition and food security forum, delegates have called for inclusion of nutrition objectives into national objectives (Oenema, 2016).

Nigeria aims at improving the competitiveness of aggregators, processors, and retailers with an estimated increase in the number of these small and medium enterprises (SMEs) from 21,264 in 2013 to 71,288 in 2017. Despite the increase in small and medium enterprises, 0.5%

of the enterprises are in the agricultural sector, and probably few SMEs are involved in the staple crop value chain (NBS, 2017). However, sickness and lack of funds were reported as one of the top reasons for the closure of business enterprises (NBS, 2017). The implication could be that they have a poor performance where their marginal costs are higher than the marginal revenue or lack access to affordable credit.

The remainder of the paper is structured as follows: In the next section, we present a short review of the literature in order to frame our case-study. In Section 3 we give detailed background information about cassava production in Nigeria and our research area. In Section 4 we discuss our methods, including the survey data collection and the econometric methods. In Section 5 we present descriptive statistics econometric results, and in section 6 we conclude.

4.2 Literature review

The placement of aggregators, retailers, and processors in the vitamin A value chain may be conceptualised around four factors, namely micronutrient deficiency targeting, demand and supply factors, and agglomeration (Zeller et al., 2002; Schmidtner et al., 2012). Adding a product line by aggregators, retailers, and processors is an investment decision. Firms would add a product when additional revenues are more significant than additional costs. The investment decision depends on the price of the vitamin A cassava products, additional costs of buying and selling, production factors, and policy environment (Zeller et al., 2002; Schmidtner et al., 2012). We assume vitamin A cassava is a new product line for aggregators, retailers, and processors and does not require significant additional capital investment.

The placement of VCA in vitamin A cassava value chain may be correlated with micronutrient deficiency. Governments and NGOs may provide subsidies like vitamin A cassava cuttings, training, and sensitization in LGAs with the highest micronutrient deficiency rates. At global level, biofortified priority index is used for identification of the countries for targeting based on micronutrient rates (Asero-Marfo et al., 2013). Targeting aims to achieve maximum impact as an intervention for people severely affected by micronutrient deficiency. Zeller et al. (2002) showed that the placement of group-based financial institutions in Bangladesh followed poverty targeting. Land ownership, literacy rates, access to health facilities, clean water are some of the variables are used to determine needs of communities and thus poverty (Brass, 2012; Zeller et al., 2002). Literacy rates are associated with poverty, measured as the percentage of people who can read and write in at least one language (Zeller et al., 2001). Literacy rates may be correlated with micronutrient deficiency. The literacy rates may also be spatially heterogeneous as different local government areas have varying levels of development. Studies by Siddhanta and Chattopadhyay (2017); Khanra et al. (2021) have shown that a mother's education positively affects children's nutrition outcomes thus micronutrient deficiency. Development partners create awareness through radios, food fairs, and behaviour change strategies to increase people's knowledge.

The price of *Garri* may be spatially heterogeneous across the local government areas and also determine placement of VCAs. Evidence has shown that output prices may be spatially dependent (Frederiksen and Langer, 2004). For example, when the prices in neighbouring LGA are low, consumers from other LGSs may buy *Garri* from that location where the prices have reduced. This is because agricultural products' demand and supply factors vary by location. Schmidtner et al. (2012) used distance to agglomeration centres, household income and a number of agglomeration centres to proxy price. Zeller et al. (2002) included access to markets, roads, electricity, agroeconomic conditions, income, urbanisation level and local economy commercialisation to determine the placement of group-based financial institutions. The neighbourhood effect was seen in the dairy and beef sectors, where the concentration of dairy farmers reduces milk collection costs, and beef farmers reduce slaughter costs (Frederiksen and Langer, 2004). The neighbourhood results in higher premium prices for farmers through declined transaction and marketing costs for the processors. In this study, because of data at the LGA, input prices were not considered in the model.

Agroecological conditions may affect the density of aggregators because they influence the production of vitamin A cassava (Badewa et al., 2022; de Oliveira et al., 2020; Daryanto et al., 2016). For example, Badewa et al. (2022) showed that vitamin A cassava's dry matter and carotene content were higher in the drier areas. Daryanto et al. (2016) found yield reduction due to drought in cassava against the common belief that the crop is drought resistant. The soil type, topography and microclimate are spatially heterogeneous, resulting in a particular production system. Evidence in the organic sector has shown organic farmers are systemically concentrated in regions with low-quality soils and steep slopes (Bichler et al., 2005; Pietola and Lansink, 2001). Farmers in areas with lower intensification potential are more likely to practice organic agriculture due to lower opportunity costs. Though there is little empirical evidence about aggregators, processors, and retailers' location and agroecological conditions, we hypothesize that they are spatially distributed to the extent that these agroecological exhibit spatial patterns. Schmidtner et al. (2012) measured agroecological conditions using the soil climate index and total annual precipitation.

The density of the value chain actors (VCA[9]) may be because of economic geography. Previous studies used agglomeration to explain the concentration of non-agricultural industries and organic farming (Ziga et al., 2019; Schmidtner et al., 2012; Wollni and Camilla, 2013). Agglomeration is based on economies of scale where firms reduce unit costs due to labour and technology polling (Krugman, 1996; Fujita et al., 1999). The studies in organic farming indicated that the decisions of neighbour farmers affected the adoption of technologies by other farmers. This body of literature does not include staple crop value chains in the agricultural sector.

Much as location of VCA is important for our study, we extend the paper to include the performance of VCAs. Specifically, our interest is in the effect of contracts on performance because it reduces transaction costs (Hobbs & Young, 2001). Transaction costs theory predicts contracts to be more common under conditions of uncertainty (Swinnen and Vandeplas, 2011). Numerous empirical studies on the impact of contracts have found that contract farming has a positive impact on farm-gate prices, farm productivity, and farm household income. According to a recent review of 30 empirical studies on contracts in developing countries (Minot and Sawyer, 2016), contracts improve farm productivity and income, with income effects ranging from 25 to 75%. Contracts, on the other hand, have been shown in various studies to be somewhat exclusive because participation is biased toward relatively better off farmers among the smallholder population (Freguin-Gresh, d'Haese, & Anseeuw, 2012; Maertens & Swinnen, 2009; Simmons et al., 2005). Furthermore, contract-farming schemes are estimated to cover only a very small proportion of smallholder farms in developing countries (between 1% and 5%) (Minot & Sawyer, 2016). There have been few studies on the effect of contract value chain actors.

4.3 Cassava production

Cassava is an important staple crop in developing countries, especially in Nigeria where households allocate 50% of their cultivatable land (HarvestPlus, 2017). The cassava production in Nigeria was estimated at 60MT, with 2.8% being vitamin A cassava. Out of the cassava that is produced, nearly 70% is being processed into *Garri*-cassava flour and *Fufu* cassava bread (GAIN and HarvestPlus, 2019). Also, cassava contributed 11% to per capita calorie supply in

[9] Aggregator primarily buys biofortified crop produce from farmers, bulks, stores and sometimes package and transports to sell in other markets. A processor mainly buys raw biofortified crop, manipulates the form of the produce, package, store and sell. They may also offer processing services to other people. Retailers purchase raw or processed biofortified crops/produce and sell them to end users called consumers.

2019 (FAO, 2022; Ikuemonisan et al., 2020). Though more investment has been made in supply-side activities like breeding nutrient rich cassava varieties, these alone may not provide sustained production of vitamin A cassava. The central challenge policymakers grapple with is to address high micronutrient deficiency rates among small-scale farmers with predominantly cassava diets.

4.4 Materials and Methods

4.4.1 Data

We analysed the distribution and performance of aggregators, retailers and processors using unique data from HarvestPlus monitoring survey, living measurement survey (LSMS) of Nigeria 2018, Nigeria Administrative Division and Global weather database. The monitoring data set has three rounds. The three rounds of data were collected from aggregators, retailers, and processors in 2019, 2021 and 2022. The data collected by HarvestPlus aimed to assess the outcome indicators, including throughput, sales, prices, variable costs, and contracts (HarvestPlus, 2022). The first round, collected in 2019, aimed to map Nigeria's vitamin A value chain actors. A total of 850 VCAs were listed (149 aggregators, 411 processors and 300 retailers). The value chain actors were mainly from southern Nigeria, the major cassava-producing region. A random sample of value chain actors for the second and third round data collection in 2021 and 2022 was constructed based on the mapping exercise of 2019. A panel of 66 aggregators, 62 retailers, and 63 processors were interviewed in 2021 and 2022. Data was collected on socioeconomic characteristics, throughput, variable costs (transport, market levies, packaging, labour), prices, participation in contracts and access to credit.

To explain the determinants of the distribution of value chain actors, we used data from the HarvestPlus mapping exercise, local government area level data from the 2018 Nigeria living standard measurement survey (LSMS), population density data from Nigeria Administrative division website and historical weather data from global weather database. The LSMS is a nationally representative data set that was collected from 743 LGAs covering agriculture, food security, credit, non-farm enterprises, labour, shocks, consumption, and expenditure. The data from HarvestPlus was georeferenced at the LGA level using the latest published GIS vector data, forming the unit of merging the two data sets. The concentration of the value chain actors was at the LGA level from the monitoring survey and then average values of independent variables, for example, the area under cassava and average per capita income estimated per LGA from the living standard measurement survey data set.

4.4.2 Theoretical framework

We are guided by the firm's neoclassical theory, where aggregators, processors, and retailers aim to sell vitamin A cassava products to maximise profits and minimise costs (Purvis, 1976). Following Feder et al. (1985), the cost function was modified to include contracts and output prices. Focusing on contracts in the cost function, we follow the Cobb Douglas cost function of the form:

$$y_{it} = e^{\beta_i} \left(\Pi_{i=1}^{k} x_{ijt}^{\gamma_j} \right) e^{u_{it}} \quad \text{......} 4.1$$

Where y_{it} is the cost per unit of vitamin A cassava bought, $x_{ijt}^{\gamma_i}$ are factors that affect costs depending on whether the value chain actor has contracts, β_i are the parameters in the cost function and u_t are compound error terms. The error term consists of two parts, θ_i the value chain actor specific characteristics, which are assumed to be unobserved and known, for example, management skills, while ε_i are unknown and uncorrelated with themselves and x_{ijt} (Heckman and Honore, 1990; Suri, 2011).

$$u_{it} = \theta_i + \varepsilon_i \quad \text{......} 4.2$$

We linearise the Cobb-Douglas cost function substituting for the decomposed error term as in equation 4.3.

$$y_{it} = \beta_i + x_{it}\gamma_j + \theta_i + \varphi_i + \varepsilon_{it} \quad \text{......} 4.3$$

Following Jaffrey et al. (2019), the model in equation 4.3 is modified to include a dummy variable for contracts. The coefficient on the contract term depends on the unobservable variable θ_i and is correlated with contracts. This is the generalization of the fixed effects model (Suri, 2006). A fixed effects model is equivalent to limiting θ_i to zero, so the VCA unobservable has the same effect on the cost per kilogram regardless of the contract. Intuitively, this assumes that the unobserved heterogeneity that makes the contract decision endogenous is independent of a VCAs ability to use contracts. The correlated random effects (CRE) model relaxes this assumption and allows the unobserved effect to vary by contract.

4.4.3 Econometric specification

We start our empirical specification for the study with determinants of distribution of aggregators, processors, and retailers. Two challenges are associated with modelling the determinants of distribution of VCA. These are 1) identification of independent variables for factors that affect supply of Garri only and 2) endogeneity. There are no independent factors that affect the demand for vitamin A cassava products, micronutrient deficiency, and supply of vitamin A cassava products only. For instance, infrastructural, community endowments and urban development affect micronutrient deficiency, demand for vitamin A cassava products and profit of the actors. As such, we modelled common factors affecting the density of value chain actors in a reduced-form model (Zeller et al., 2002). In the modelling of the determinants of density of VCA, we assume that a value chain actor operates within a local government area but can be affected by characteristics and interaction of value chain actors in the neighbouring local government areas.

The second challenge is endogeneity where demand and micronutrient deficiency factors may be endogenous with the density of value chain actors in a local government area. The characteristics of value chain actors may show attributes that will make them more concentrated in some locations. In that, factors that affect the density of value chain actors may be spatially heterogeneous and dependent. Such endogeneity is addressed using instrumental variables (Ambali et al., 2021; Kelejian and Piras, 2014). We added lagged spatial weight as an instrument to correct this endogeneity, and secondly, the independent variables are potentially lagged variables. Bellemare et al. (2017) noted that lagged explanatory variables may be used to correct for endogeneity under some appropriate conditions. The model is specified as follows:

$$y = \beta_0 X + \rho_1 Wy + \rho_1 Wx + \varepsilon \quad \text{......} 4.5$$

Where y is the number of value chain actors in the 100000 population, it is calculated by dividing the number of value chain actors by the population of the LGA and then multiplying by 100000. Wy is the spatial lag weight on the number of value chain actors in an LGA, which may be used as an instrumental variable in the model, and X is a vector of exogenous variables that affect the density of value chain actors. Wx is the spatial lag on the price of *Garri*. Lagged price of *Garri* is included conceptually as consumers of vitamin A cassava in nearby LGAs are tempted to buy *Garri* from areas where price advantage exists (Baltagi and Levin, 1986). For robust checks, we estimated a spatial lag error model.

We included the following variables in the model: cassava production per capita measured as the household cassava production divided by household size, indication of investment potential. The cassava production per capita is a variable that we hypothesize to be positively correlated with the density of value chain actors. The literacy rate is the percentage of the population that can read and write. Electricity coverage is important for the operation of the cassava milling machines and was measured as the percentage of households that are connected to the grid. The distance to market and all-weather road was one of the infrastructural variables that were measured in kilometres. We also included population density per square kilometre, average household income in the local government area, rainfall, percentage of households that own livestock and price of white *Garri*.

4.4.4 Effects of contracts on the performance of the value chain actors

To determine factors that affect the performance of VCAs, we employed the correlated random effects model. The correlated random effects model was specified as follows.

$$y_{it} = \beta_0 + \beta_1 x_{it} + \beta_2 c_i + \pi \bar{x}_i + v_i + \varepsilon_{it} \qquad \text{4.6}$$

where y_{it} is the price margin per kilogram or cost per kilogram, x_{it}, are variables related to value chain actors like age, education level, c_i variables related to cassava, for example, the price of white *Garri*, v_i is the value chain actor error and ε_{it} is the cassava product error, and β, π are parameter estimates. Estimating the CRE model requires two assumptions of independence of the composite error term and exogenous regressors. The cluster means of the number of contracts picks up any correlation between contracts and the errors related to value chain actor characteristics, also known as "cluster mean centering" (Halaby, 2003). Jeffrey et al. (2012) noted that controls might not eliminate unobserved heterogeneity, so the results may be biased, and therefore the results of the CRE model must be interpreted considering that limitation.

In this study we used price margins and cost per kilogram were used to measure the performance of aggregators, processors, and retailers (Hoang, 2021; Ordofa et al., 2021; Goeb et al., 2021). Price margin per kilogram is the difference between buying price and selling of *Garri*. The cost per kilogram is the total variable costs (packaging, transport, warehouse, packaging) divided by the annual volume bought. The dependent variable was measured as dummy (1 contract with suppliers of Garri, 0 no contract). We included the number of employees, price of white *Garri*, number of other VCAs, education, sex, and experience in the business as control variables. A rich set of control variables would address the challenge of strict exogeneity in correlated random effects model (Jeffrey et al., 2012).

4.5 Results

We start our analysis by drawing the localized map regions using spatial weight values for the concentration of value chain actors to show their distribution. The Local Indicators of Spatial Association (LISA) cluster map is based on spatial corelation between the value chain actors. The blue coloured areas are where we find a high density of value chain actors and have neighbouring local government areas with high concentration of value chain actors, as such, are primarily found in the southern states, which is consistent with the cassava producing states. This would primarily suggest that value chain actors are found in cassava producing areas.

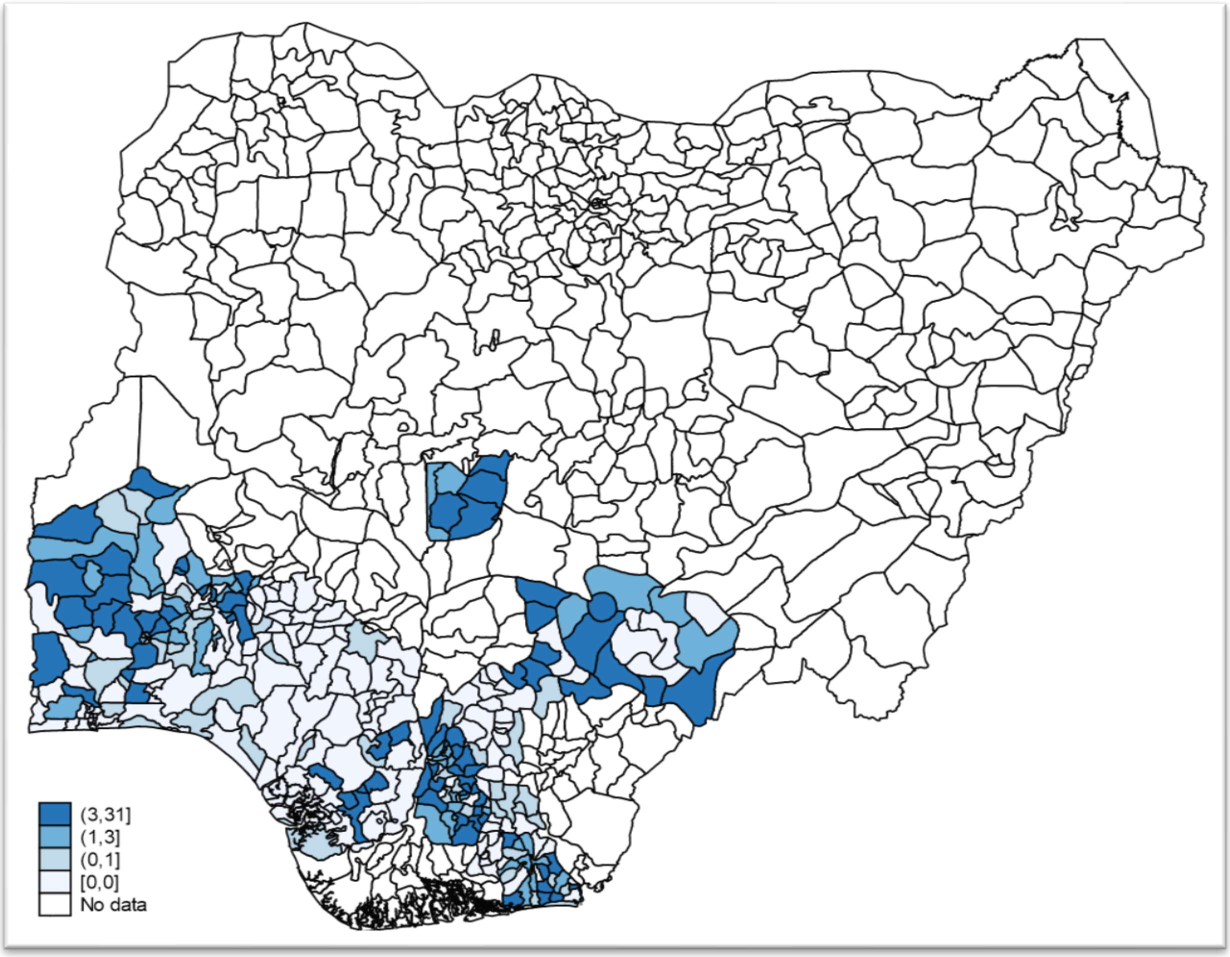

Figure 4. 1 LISA cluster map for value chain actor in vitamin A food value chain

4.5.1 Descriptive results for the distribution of value chain actors

Generally, the average annual per capita income was 29,494 Naira translating into 0.51 dollars[10] daily, below the 1.9-dollar global poverty line. The percentage of households with

[10] Exchange rate of 158 for Nigeria PPP (IMF, 2023)

access to electricity was 17 though the national target is to get 90% of people connected to the national grid (NDP, 2021). The mean price of *Garri* per kilogram was 140 Naira and average cassava production was 823kg per capita. The average population density of 2,791 per square kilometre, driven by southern cassava producing states in Nigeria. The average distance to the nearest road and market was 14 kilometres indicating rural local government areas. The VCAs differed in access to electricity, distance to the road, phone penetration and population density.

Table 4. 1 Descriptive statistics of LGA level variables in the distribution of value chain actors

Variables	**Pooled** n=314	**Low VCA density** n=244	**High VCA density** n=70	**Difference**
Percentage of households that own livestock	0.47	0.46	0.51	0.05
Percentage of people that can read and write	0.64	0.63	0.66	0.03
Percentage of households connected to the national grid	0.17	0.16	0.22	0.06***
Average per capita income (Naira)	29,494	29,101	30,902	1801
Distance to the nearest market (Km)	14.9	15.25	13.63	-1.62*
Distance to the nearest road (Km)	14.8	15.16	13.55	-1.61**
Price of *Garri* (Naira) per Kg	140	134	159	25.21**
Average annual rainfall (mm)	1769	1803	1644	-159
Phone penetration (%)	0.29	0.27	0.38	0.11***
Population density (people per square Km)	2791	1,412	7,697	6284***
Cassava production (Kg) per capita	823	871	585	-286

Source: Own calculation based on Living standard measurement survey (LSMS) 2018; Nigeria administrative division data and Global weather database

4.5.1 Determinants of the placement of aggregators, processors, and retailers

Table 4.2 presents the results of the spatial lag model and the results of autocorrelated error model estimates are also shown in Table A4.1. We estimated equation 4.5 for aggregators, processors, and retailers and all VCA. The model for all VCA was motivated by complementarity between the VCAs, for example aggregators supply processors with vitamin A cassava which is processed into *Garri* and sold to consumers by retailers.

The coefficient of cassava production per capita was significant at 5 percent (Model 4). In other words, a one percent increase in the per capita cassava production leads to a reduction in the number of VCA by 0.00059 per 100,000 people. With a total population of 80 million people in 13 states, the result translates into a reduction of one value chain actor. Also, average annual rainfall was associated with a reduction in the number of VCA. An increase in average rainfall by one millimetre led to a reduction of 3 VCA. Average rainfall and cassava production per capita are supply variables and seem to suggest that the placement of VCA is more in areas with less production of cassava. The effect of cassava production and average rainfall is consistent across the autocorrelated error model (Table A4.1). The results showed that the placement of VCA is correlated across LGAs. The positive sign of the spatial lag coefficient implies that the placement of value chain actors in neighbouring LGA positively influences the density of value chain actors, depicting agglomeration effects. An increase in the density of value chain actors by one percentage point increases the density of value chain actors in the neighbouring LGA by 1.8 percentage points.

Like in model 4, the coefficient of cassava production per capita and average annual rainfall was significant for aggregators only not processors and retailers. For instance, a one percent increase in the per capita cassava production led to a reduction in the number of aggregators by 0.00056 per 100,000 people. The result translates into a reduction of one aggregator. Also, average annual rainfall is associated with a reduction in the number of aggregators. An increase in average rainfall by one millimetre led to a reduction of 3 aggregators. Average rainfall and cassava production per capita are supply variables and seem to suggest that the placement of aggregators is more in areas with less production of cassava.

Ownership of livestock, price of *Garri*, and average per capita income are associated with the placement of retailers and aggregators. An increase in the percentage of households that own livestock by one point increases the density of retailers by 0.5 per 100,000 people. As expected, an increase in the price of *Garri* was associated with an increase in the number of retailers. With an increase in the price of Garri by one percent the number of retailers increases by 0.7 per 100,000 people.

The coefficient for the percentage of households that can read and write was negative and significant at 10 percent for processors and not aggregators. That means processors are found in locations with less poverty levels or micronutrient deficiency levels. These locations could be LGAs that have low poverty rates. The percentage of households that own smartphones was negatively associated with the density of aggregators and positively with the density of processors. The average distance from the household to the market was associated with the number of retailers. It appears placement of retailers is mindful of the transaction costs (Zeller et al., 2001).

The response of VCA because of other VCA was captured by including the density of the VCA in equation 4.5. On one hand, this may signal the complementarity of services or products while on the other hand, it may mean competition. The results suggest that the density of aggregators correlates with the presence of processors. The presence of retailers and aggregators correlates with the density of processors. Lastly, the density of retailers correlates with the presence of processors.

Table 4. 2 Spatial lag model estimates for determinants of the density of value chain actors

Variables	Aggregator	Processors	Retailers	VCA
	1	2	3	4
Average per capita income in the LGA in 2018	0.034*	-0.083	-0.012	0.023
	(0.020)	(0.066)	(0.042)	(0.021)
Cassava production per capita	-0.056**	0.075	-0.039	-0.059**
	(0.025)	(0.083)	(0.053)	(0.027)
Percentage of households connected to the national grid	-0.044	0.805	-0.445	-0.010
	(0.150)	(0.496)	(0.315)	(0.164)
Percentage of households that own livestock	-0.067	0.183	0.455***	-0.010
	(0.081)	(0.271)	(0.170)	(0.087)
Percentage of people that can read and write	-0.087	-0.922*	-0.026	-0.251
	(0.162)	(0.534)	(0.340)	(0.173)
Average Phone penetration (%)	-0.384**	1.468***	-0.507	-0.260
	(0.168)	(0.559)	(0.357)	(0.186)
LGA level price of Garri (Naira) per Kg	0.138	-0.559	0.705***	0.148
	(0.106)	(0.355)	(0.222)	(0.114)
Average annual rainfall (mm)	-0.401***	0.151	0.302	-0.377***
	(0.138)	(0.356)	(0.225)	(0.138)
Average distance from households to the nearest market (Km)	-0.029	0.150	-0.360***	-0.053
	(0.050)	(0.168)	(0.105)	(0.053)
Population density	0.014	0.021	0.003	0.016
	(0.020)	(0.060)	(0.038)	(0.020)
Average distance from households to the nearest road (Km)	0.022	-0.166	0.033	0.019
	(0.067)	(0.226)	(0.143)	(0.073)
Retailer density	0.012	0.702***		
	(0.026)	(0.079)		
Processor density	0.099***		0.282***	
	(0.016)		(0.032)	
Aggregator density		1.118***	0.052	
		(0.177)	(0.119)	
Spatial lag term ρ	-0.295	1.321	0.593	1.777**
	(0.585)	(0.906)	(0.703)	(0.842)
Constant	2.773**	1.301	-3.902*	2.755**
	(1.146)	(3.240)	(2.042)	(1.159)
N	321	321		321
Wald chi2	87.67	180.89	153.3	20.65
Prob chi2	0	0	0	0.037
Pseudo R2	0.218	0.358	0.319	0.077

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1. The figures in the brackets are standard deviations. *** p<0.01, ** p<0.05, * p<0.1

4.5.3 Descriptive statistics for the effects of contracts on performance

After exploring the determinants of the location of aggregators, processors, and retailers, we turn to their performance. We explore the hypothesis that contracts are associated with the costs per kilogram and price margin per kilogram. From descriptive statistics, contracts seem to reduce the cost per unit output and increase the price margin, contrary to our expectations (table 4.3). Aggregators with contracts have a lower cost per output and higher price margins. Contracts may be associated with low cost per output and price margins for VCAs because of the firm's size and the business's age. Aggregators with contracts are small-scale and have more experience aggregating cassava than those without contracts. Unlike aggregators, the processors with contracts have higher price margins and cost per output unit than those without contracts, though the difference is insignificant.

Table 4. 3 Descriptive statistics of the sampled aggregators, processors, and retailers

Variable	Aggregators			Processors			Retailers		
	No contract	Contract	Difference	No contract	Contract	Difference	No contract	Contract	Difference
Price margin per Kg	31.16 (47.25)	54.61 (67.29)	23.45**	28.84 (22.39)	33.79 (21.70)	4.94	44.11 (49.79)	59.71 (67.46)	15.59
Cost per Kg	4.69 (7.02)	2.63 (4.68)	1.49	4.43 (4.03)	5.08 (4.98)	0.65	2.31 (0.40)	1.12 (1.65)	1.19
Number of employees	4.19 (3.68)	2.78 (2.83)	1.42**	5.44 (8.03)	5.84 (6.96)	0.40	2.20 (4.02)	2.94 (2.79)	0.73
Sex of the VCA owner	0.39 (0.49)	0.24 (0.44)	0.15	0.53 (0.50)	0.42 (0.49)	0.11	0.81 (0.39)	0.53 (0.50)	0.28
Price of white *Garri* per Kg	73.64 (59.43)	109.51 (61.93)	35.88**	103.89 (70.80)	112.37 (87.47)	8.48			
Age of the firm	3.42 (2.03)	4.37 (2.88)	0.95**	9.95 (5.17)	14.76 (7.67)	4.81***	10.22 (8.59)	14.32 (8.75)	4.10**

The figures in the brackets are standard deviations. *** p<0.01, ** p<0.05, * p<0.1

4.5.4 Effects of contracts on costs per kilogram of aggregators, processors, and retailers

Our theoretical framework sets the model in terms of Cobb Douglas cost function, where the dependent variable is logarithm of cost per kilogram. The results from the correlated random effects model are presented in table 4.4. Contracts reduce the cost per kilogram for aggregators. An aggregator with contracts pays 67% less per kilogram than those without contracts. The results from the fixed and random effects models are consistent with estimates from the correlated random effects model. The reduction in costs translates into 2 Naira savings in variable costs per kilogram with contracts. One of the explanations for these negative effects on unit costs is high guaranteed quantities of cassava to purchase for aggregators. Results from the descriptive statistics attest to this assertion. Theoretically, contracts reduce transaction costs for economic actors. FAO (2013) alludes to transaction costs in rural economies due to missing input markets, substantial information asymmetries in output markets, and small-scale farming production units. Number of employees and price of *Garri* was associated with cost per kilogram. In model 4, contracts reduce retailers' cost per unit by 95% which translates into 2.5 Naira reduction in cost per kg. Retailers with primary education had lower costs than those without formal education. This could be because education expands people's choices and improves decision-making. The number of competitors increases the cost per kilogram for retailers. This may be due to competition that makes firms to incur more costs (Xuan and Thi, 2022).

Table 4. 4 Model estimates of effects of contracts on costs per unit for aggregators, Processors and Retailers

Variables	Aggregators	Processors	Retailers
	1	2	3
Contracts (1=yes)	-0.951***	0.068	-0.672*
	(0.321)	(0.250)	(0.362)
Mean of contracts	1.058*	-0.187**	-0.056
	(0.632)	(0.074)	(0.053)
Number of employees		0.010	0.026
		(0.013)	(0.026)
Price of white Garri (Naira)	0.545***	0.158	
	(0.179)	(0.218)	
Number of competitors	-0.010	-0.025	0.026***
	(0.039)	(0.017)	(0.009)
Education (1=tertiary)	0.166	-0.286	-0.585*
	(0.454)	(0.229)	(0.300)
Education (1=secondary)	0.073	-0.274	-0.510
	(0.422)	(0.285)	(0.348)
Sex (1=female)	0.410	-0.749***	0.117
	(0.290)	(0.214)	(0.303)
Experience in the business (years)	-0.081	-0.006	-0.097
	(0.200)	(0.168)	(0.136)
Loan (1=yes)	-0.268	0.072	0.371*
	(0.331)	(0.223)	(0.212)
Training (1=yes)	-0.265	0.135	-0.311
	(0.268)	(0.167)	(0.336)
Constant	-0.893	3.959***	2.853***
	(1.129)	(1.183)	(0.845)
Observations	132	124	126
N	66	62	63

The dependent variable is Ln cost per unit output. Covariables include the number of employees, price of white *Garri*, number of other aggregators, education of the aggregator, sex of aggregator, and experience in the business. The figures in the parenthesis are the standard errors. *** p<0.01, ** p<0.05, * p<0.1.

4.5.5 Effects of contracts on the price margin per kilogram of aggregators, processors, and retailers

We estimate the effect of contracts on price margin using equation 4.5 with log price margin per kilogram for aggregators, retailers, and processors as the dependent variable. We then included time-invariant factors like education level, experience, and sex of the business owner. The results in the correlated random effects model are presented in Table 4.5. Contracts have an insignificant negative effect on the price margin of aggregators and insignificant positive effect on processors and retailers. Other factors affecting the price margin for vitamin A cassava are the price of white cassava, number of other value chain actors, and number of employees. An increase in price of white cassava increases the price margin for vitamin A cassava. In other words, it makes vitamin A cassava expensive, which may be due to the co-movement of prices as general price increases due to macroeconomic shocks (Palaskas and Varangis, 1991). The number of employees increases the price margin, and competition reduces the price margin as expected.

Table 4. 5 Model estimates for effects of contracts on price margin of aggregators, processors, and retailers

Variables	Aggregators	Processors	Retailers
	1	2	3
Contracts (1=yes)	-0.029	0.030	0.434
	(0.344)	(0.170)	(0.263)
Mean of contracts	-0.282	0.039	-0.035
	(0.438)	(0.056)	(0.026)
Number of employees		0.026**	-0.068**
		(0.013)	(0.034)
Price of white Garri (Naira)	0.668***	0.527***	
	(0.153)	(0.184)	
Number of competitors	-0.081***	-0.016	-0.007
	(0.024)	(0.012)	(0.010)
Education (1=tertiary)	0.544**	0.065	-0.252
	(0.246)	(0.317)	(0.254)
Education (1=secondary)	0.087	0.073	-0.583**
	(0.217)	(0.300)	(0.260)
Sex (1=female)	-0.015	-0.039	-0.173
	(0.159)	(0.134)	(0.246)
Experience in the business (years)	-0.123	0.376***	0.204
	(0.111)	(0.124)	(0.125)
Loan (1=yes)	0.019	0.164	0.523**
	(0.227)	(0.156)	(0.221)
Training (1=yes)	0.339*	-0.187	-0.025
	(0.196)	(0.181)	(0.216)
Constant	0.214	2.011*	2.778***
	(0.883)	(1.097)	(0.662)
Observations	132	124	126
N	66	62	63
Robust standard errors in parentheses			
*** p<0.01, ** p<0.05, * p<0.1			

Dependent variable is Ln price margin per Kg. Covariables include the number of employees, price of white *Garri*, number of other aggregators, education of the aggregator, sex of aggregator, and experience in the business. The figures in the parenthesis are the standard errors. *** p<0.01, ** p<0.05, * p<0.1.

4.6 Discussions

We investigated the determinants of the density of aggregators, processors and retailers and the effect of contracts on costs per kilogram and price margin. The results indicated that the processors and retailers are likely found in local government areas with high demand for cassava products with better road networks. Specifically, the price of *Garri*, per capita income and livestock ownership influence the density of retailers. One of the explanations for this could be from Keynes law, where demand creates its supply (Fazzari and González, 2020; Smith, 2012). In other words, an increase in consumer demand for cassava products in the market drives prices upwards, which induces more retailers to enter the market as higher prices may result in higher profits. This may be a short-run phenomenon because, in the long run, increased density of value chain actors may result in perfect competition that reduces commodity prices. Secondly, the desire for the VCA to reduce transaction costs makes them operate in areas that have better road networks. The association of cassava production per capita and all value chain actors, aggregator density was significant. Much as NGOs and development partners may target households directly by distributing planting material, increasing either the area under cassava or production per capita, this translates into the emergence of aggregators in locations with high demand for vitamin A cassava products.

Studies in agriculture have demonstrated the importance of neighbouring farmers in adopting technologies (Wollni and Andersson, 2014; Schmidtner et al., 2012). We found that the density of value chain actors in one local government area influences the location of VCA in the neighbouring local government areas. This agglomeration is because of economies of scale where value chain actors benefit from a poll of technologies, labour, and information availability within those locations (Fujita et al., 1999; Krugman, 1996). As a result, production costs for the aggregators, retailers and processors are reduced. When we introduced complementarity variables, we show a positive correlation among value chain actors.

We have demonstrated that contracts reduce the costs per kilogram for value chain actors. Contracts reduce the variable costs for aggregators by about more than half the total variable costs. Results from Mishra et al. (2018); Engindeniz (2007) found that contracts negatively affect the cost structure of smallholder farmers. The contracting mechanism reduces costs per kilogram through increased product purchases of aggregators, and retailers. Value chain actors face risks regarding the quantity and quality of *Garri* procured from farmers. With contracts, uncertainty, bounded rationality, and opportunistic behaviour of the contracting partner is reduced. In addition, contracts increase the trust between farmers and value chain actors. This increases the quantity of *Garri* procured by VCA, lowering the cost per unit. Yeshitila et al. (2020) have shown trust makes farmers honour their contracts. Fischer and Wollni (2018) found trust were economically significant in determining the willingness to pay for high transparency in quality controls. Under perfect competition, which is the case of staple food crops in rural economies, the increased output would reduce the costs, leading to consumer welfare gains.

4.7 Conclusion

Considering the importance of aggregators, processors, and retailers in scaling biofortified crops, we investigate the determinants of the spatial pattern of value chain actors. A total of 850 VCAs in the vitamin A cassava chain were listed, and these are not randomly distributed across space, but their density was spatially clustered. The positive sign of the rho from the econometric analysis indicates that the neighbourhood effect exists and the density of VCAs in nearby local government areas affects each other. This means even the location of VCAs respond to demand factors for all value chain actors. Though aggregators are located in LGAs with low production of cassava, these areas have high per capita income. Retailers are also located in LGAs with higher prices and good road network. This is presumably out of a desire to increase profits. In general, all the value chain actors are located in LGAs with low production where they can benefit from agglomeration effects. The results indicates that contracts are important for cost reduction by the value chain actors while they do not have an effect on the price margin. The cost reduction effects of contracts may be due to increased volumes of Garri traded. This means that to achieve consumption by the large community, contracts would be encouraged.

Our results have implications for scaling technologies through value chain actors in developing countries. Policy needs to focus on creating enabling environments so that VCAs can contract with farmers. Also, joint neighbourhood initiatives are most appropriate to address the negative externalities of scaling biofortified crops on nearby local government areas. Donor and government support through subsidies and training of farmers would increase production and reduce transaction costs.

One of the limitations of our study was endogeneity. Contracts may be correlated with the error term, which makes the estimates biased. Though we have used the CRE model, the model cannot entirely correct the correlation between contracts and the error term. In such cases, the results can be interpreted cautiously or as an association between contracts and outcomes instead of causal effects. Secondly, the mapping of the aggregators, processors and retailers may not be compressive due to limited resources, subsequently affecting the second and third-round survey sample size. A more robust study that includes more listing of VCAs and analysis that involves comprehensive outcomes would provide evidence of contracts on aggregators, retailers, and processors' outcomes.

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Appendix for chapter four

Table A4. 1 Spatially autoregressive errors model estimates for determinants of the density of value chain actors

Variables	Aggregator	Processor	Retailer	All VCAs
	1	2	3	4
Percent of crop area under cassava in 2018	-0.001	-0.001	0.001	-0.002
	(0.006)	(0.007)	(0.006)	(0.013)
Average per capita income in the LGA in 2018	0.001	-0.118	-0.169*	-0.294
	(0.087)	(0.101)	(0.090)	(0.196)
Percentage of households connected to the national grid	-0.864	0.952	-0.357	-0.266
	(0.649)	(0.754)	(0.669)	(1.462)
Percentage of households that own livestock	0.058	0.798*	1.129**	1.993**
	(0.381)	(0.445)	(0.393)	(0.861)
Percentage of people that can read and write	0.616	-1.689*	-0.792	-1.863
	(0.744)	(0.860)	(0.766)	(1.669)
Average annual rainfall (mm)	-0.227	-0.296	0.615	0.125
	(0.508)	(0.616)	(0.529)	(1.177)
Phone penetration (%)	-0.524	1.017	0.032	0.483
	(0.796)	(0.933)	(0.823)	(1.804)
LGA level price of *Garri* (Naira)	0.001	0.007**	0.005**	0.013**
	(0.002)	(0.002)	(0.002)	(0.004)
Population density	-0.046	0.057	0.055	0.064
	(0.081)	(0.096)	(0.084)	(0.184)
Distance to the nearest road (Km)	-0.007	-0.003	-0.005	-0.016
	(0.020)	(0.023)	(0.020)	(0.044)
Distance to the nearest market (Km)	-0.002	0.001	-0.032**	-0.034
	(0.014)	(0.016)	(0.014)	(0.030)
Constant	2.525	2.759	-2.704	2.491
	(4.091)	(4.928)	(4.256)	(9.439)
Spatial autoregressive error term ρ	-0.012	0.113**	0.011*	0.068*
	(0.146)	(0.06)	(0.008)	(0.042)
N	321	321	321	321
Wald chi2	3.760	23.99	31.95	22.36
Prob chi2	0.976	0.013	0.001	0.022
Pseudo R2	0.012	0.075	0.091	0.068

Table A4. 2 Fixed effects model estimates for aggregators, processors, and retailers: unit costs

Variables	Aggregators	Processors	Retailers
	1	2	3
Contracts (1=yes)	-0.990***	-0.239	-0.207
	(0.291)	(0.349)	(0.342)
Number of employees	-0.069	0.001	0.001
	(0.067)	(0.019)	(0.037)
Price of white Garri (Naira)	-0.369	-0.337	
	(0.285)	(0.344)	
Number of competitors	0.015	-0.076***	0.000
	(0.056)	(0.016)	(0.026)
Loan (1=yes)	-0.667**	-0.464	0.239
	(0.316)	(0.343)	(0.307)
Training (1=yes)	-0.045	-0.236	0.068
	(0.296)	(0.233)	(0.487)
Constant	3.687***	6.047***	1.922**
	(1.258)	(1.650)	(0.919)
Observations	132	124	126
Number of hhid_1	66	62	63
R-squared	0.188	0.216	0.011

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table A4. 3 Fixed effects model estimates for aggregators, processors, and retailers-price margin

Variables	Aggregators	Processors	Retailers
	1	2	3
Contracts (1=yes)	-0.173	-0.233	0.270
	(0.346)	(0.262)	(0.388)
Number of employees	0.027	-0.017	-0.117***
	(0.033)	(0.020)	(0.041)
Price of white Garri (Naira)	0.995***	0.640**	
	(0.314)	(0.249)	
Number of competitors	-0.042	-0.013	0.043
	(0.043)	(0.015)	(0.029)
Loan (1=yes)	0.695*	0.020	0.658**
	(0.349)	(0.199)	(0.308)
Training (1=yes)	0.436	-0.417*	-0.214
	(0.267)	(0.243)	(0.339)
Constant	-2.399*	3.323***	2.481***
	(1.394)	(1.206)	(0.756)
Observations	132	124	126
Number of hhid_1	66	62	63
R-squared	0.330	0.165	0.196

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table A4. 4 Random effects model estimates for aggregators, processors, and retailers-unit costs

Variables	Aggregators	Processor	Retailers
	1	2	3
Contracts (1=yes)	-0.659**	0.085	-0.938***
	(0.300)	(0.246)	(0.356)
Number of employees	-0.102*	0.015	0.022
	(0.060)	(0.011)	(0.028)
Price of white Garri (Naira)	0.504***	0.058	
	(0.167)	(0.234)	
Number of competitors	-0.025	-0.040***	0.024***
	(0.040)	(0.015)	(0.008)
Education (1=tertiary)	0.380	-0.313	-0.576*
	(0.418)	(0.244)	(0.297)
Education (1=secondary)	0.307	-0.329	-0.560*
	(0.359)	(0.294)	(0.334)
Sex (1=female)	0.280	-0.771***	0.194
	(0.269)	(0.215)	(0.288)
Experience in the business (years)	0.067	-0.026	-0.167
	(0.172)	(0.167)	(0.155)
Loan (1=yes)	-0.353	0.165	0.421**
	(0.310)	(0.228)	(0.210)
Training (1=yes)	-0.338	-0.017	-0.279
	(0.265)	(0.188)	(0.330)
Constant	-0.142	3.874***	2.800***
	(1.104)	(1.285)	(0.841)
Observations	132	124	126
N	66	62	63

Table A4. 5 Random effects model estimates for aggregators, processors, and retailers-price margin

Variables	Aggregators	Processors	Retailers
	1	2	3
Contracts (1=yes)	-0.142	0.026	0.266
	(0.241)	(0.167)	(0.207)
Number of employees	0.013	0.025**	-0.071**
	(0.022)	(0.012)	(0.035)
Price of white Garri (Naira)	0.669***	0.548***	
	(0.148)	(0.179)	
Number of competitors	-0.078***	-0.013	-0.008
	(0.024)	(0.011)	(0.011)
Education (1=tertiary)	0.498**	0.071	-0.246
	(0.237)	(0.325)	(0.252)
Education (1=secondary)	0.039	0.084	-0.615**
	(0.209)	(0.309)	(0.267)
Sex (1=female)	0.013	-0.035	-0.124
	(0.167)	(0.135)	(0.228)
Experience in the business (years)	-0.146	0.381***	0.160
	(0.115)	(0.125)	(0.119)
Loan (1=yes)	0.029	0.145	0.554**
	(0.232)	(0.157)	(0.219)
Training (1=yes)	0.356*	-0.155	-0.003
	(0.197)	(0.172)	(0.217)
Constant	0.113	2.029*	2.741***
	(0.899)	(1.085)	(0.665)
Observations	132	124	126
Number of hhid_1	66	62	63

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Chapter five

5.0 Summary and policy implications

Scaling agricultural innovations, especially biofortification, has gained popularity as one of the interventions to reduce micronutrient deficiency. The drive to scale biofortification has resulted in different governments and partners implementing programs ranging from breeding to enacting policies (Foley et al., 2022; Mulongo et al., 2021). For example, over 440 biofortified crop varieties have been released globally and 41 policy documents that include biofortification as a strategy for reducing micronutrient deficiency were developed in India (Foley et al., 2022). Several studies have shown that biofortification can lead to an increase in micronutrient intake (Murray-Kolb et al., 2017), that it can be scaled (Rodas-Maya et al., 2022), and that the intervention faces governance challenges. No studies have identified the governance challenges and test innovations that can scale biofortified crops like contracts.

The research questions examined in this thesis seek to address important areas in reducing micronutrient deficiency. This thesis explores first the long-term trends in prices of micronutrient-rich foods and calorie-rich foods. Second it provides insights into the governance challenges in implementing large scale biofortification program Thirdly, the thesis provides evidence on approaches to increase the accessibility of the biofortification through contracts.

5.1 Empirical findings

Literature has shown that healthy foods are expensive. In Chapter 2, we extend that analysis by estimating the long-term price trends and volatility of micronutrient-dense and starchy staples, as well as identifying factors that have sustained food commodity price growth. The findings of this study support our hypothesis that the prices of micronutrient-dense foods rise faster than those of calorie-dense foods. Expressly, according to the findings, prices for micronutrient-rich foods increased in real terms by 0.03% per month more than prices for starchy staple foods, with a 12% growth difference predicted over the next 30 years if past trends would continue to persist into the future. Many reasons could explain the growing price divergence between foods high in micronutrients and foods high in calories. First, higher income elasticity of micronutrient dense foods compared to calorie dense foods. The study has shown that as incomes increase the price gap between staple food and micronutrient dense foods becomes wider. Secondly, the higher production level of calorie-dense foods like rice, maize and maize compared to micronutrient-dense foods may have caused price trends to persist. The findings also revealed that the prices of micronutrient-dense foods in domestic markets are more volatile than those of calorie-dense foods. One of the reasons could be the nature of micronutrient-dense foods. Micronutrient-dense foods are perishable and necessitate significant investment in value chain storage and transportation.

In chapter 3, as one of the scaling pathways, we assessed the governance challenges confronting farmers, seed multipliers, aggregators, processors, and retailers and empirically test whether information provision through training can reduce the identification governance challenge. From the conceptual framework, we identified governance challenges in scaling biofortified crops at state, market, and community level. The results support the hypothesis of the existence of governance challenges that impede the achievement of the outcomes of scaling biofortified crops. Corruption in the supply of OFSP vines and household's unwillingness to allocate more land for OFSP are examples of governance challenges. Furthermore, traders and village merchants adulterate iron beans consumers are unwilling to pay a premium for OFSP roots and iron bean grain. In general, the governance challenges may result from information asymmetry about biofortified crop products, biofortified crops considered as merit goods, collective action problems, and free riding by value chain actors. The results did not support the hypothesis that information provision can improve the identification of iron beans. Though the effects of training farmers on identification are positive, they were insignificant. Similar results on the difficulty in identifying biofortified crop varieties that have invisible traits were highlighted by Pérez et al. (2018).

The fourth chapter provides evidence on determinants of distribution and performance of aggregators, retailers, and processors in Nigeria's vitamin A value chain. In this chapter, we have tested two hypotheses. The first hypothesis supply factors influence the distribution of aggregators, processors, and retailers. The second hypothesis was that value chain actors with contract have reduced costs per kilogram and price margin. The results showed that the value chain actors' distribution was not associated with the supply factors. The location of value chain actors was associated with price of *Garri* and livestock ownership. The results from the effects of contracts on performance support the hypothesis that contracts reduced costs per kilogram for aggregators and retailers. One explanation would be the increased volume of purchases for value chain actors with contracts.

5.2 Policy and program implications

This thesis contributes to a growing body of literature on the scaling of biofortified crops by providing evidence on the governance challenges and contracts to reduce the transaction costs in the staple crops value chains. This dissertation's findings have several policy implications that could be used to implement biofortification programs and scaling of other interventions.

Governments and development partners should invest in nutrition-sensitive agriculture interventions such as biofortification, high-yielding fruits and vegetables, and livestock. Evidence have shown that these interventions can reduce micronutrient deficiency (Bouis and Saltzman, 2017; Hetherington et al., 2017; Kabunga et al., 2014). In chapter two, the results showed that the hypothesized causal factors may make it plausible that prices for micronutrient-dense foods will continue to rise faster than prices for starchy staple foods in the near and long term. Therefore, investments like biofortification that would make calorie-dense foods richer in micronutrients would enable poor households to access and increase iron, zinc, and vitamin A intake. Governments may mainstream biofortification into their national breeding programs and national policies. This would increase the number of crop varieties with higher micronutrients available to farmers.

It is important that legislation is put in place by government to regulate and implement the supply of OFSP vines and vegetative planting material. The regulation must allow for the certification of vine multipliers and government and NGO need to procure from certified sources. Efforts to certify the vine multipliers are already in place, but procurement enforcement from certified sources seems to be weak. In chapter 3, the results have shown that vine multipliers face corruption challenges in supplying vines to sub-counties and NGOs. Therefore, regulation of vine supply by the state would reduce bribery in the seed system of orange-fleshed sweet potatoes.

Providing subsidies for iron bean and OFSP planting materials through government and NGO programs may be a viable way to address some of the governance challenges, as access to seed increases the production of biofortified crops. The results in chapter 3 highlight the governance challenges of adulteration because invisibility of the micronutrient in the crop variety, especially iron beans and OFSP vines. Subsidies would increase the production levels of iron beans and OFSP so that markets would be saturated. This increases the probability of buying biofortified crops from the market, thus increasing the intake of iron and vitamin A.

A conducive environment for contracting between value chain actors and farmers should be created by governments and non-governmental organizations. As a result of regulatory changes in the cassava value chain to improve the quality, input subsidies, access to credit, collective marketing, and rural infrastructural development, the cassava supply can directly increase, and the contracting can be indirectly increased. Results from chapter four indicated that value chain actors could reduce their cost per output and reduce their price margin when they have contracts.

5.3 Methodological implications

This dissertation contributes to the literature by employing various methods and techniques, including qualitative, and advanced quantitative methods in impact evaluation using observational studies and time series analysis. (Hernán and Robins, 2020; Abadie and Cattaneo, 2018; Imbens and Wooldridge, 2009). In Chapter two, we used advanced time series methodologies, for example, autoregressive and panel autoregressive distributed lag models, to disentangle trends and volatility in prices of crop commodities in addition to simple averages. In Chapter 3, we applied qualitative approaches like the Process Net-Map tool to identify actors and elicit governance challenges in the scaling of biofortified crops and correlated random models to determine the effects of information provision on identifying iron beans in data collected from field lab experiments. In Chapter 4, we used spatial and correlated random effects models to answer research question three. This thesis has expanded the use of these methods discussed above in agricultural economics.

5.4 Limitations of the study

In chapter two, the main limitation was price data availability. The available price data on calorie-dense food commodities and micronutrient-dense foods does not include some major crops; worse still the time series was not long enough to conduct rigorous analysis. Ideally, all countries' data periods should be the same, and the food items chosen should include all of the country's main starchy staples and micronutrient-dense foods. Despite the study's limitations, it is a good starting point for investigating the price differences between starchy staples and micronutrient-dense foods. More research on this topic is needed on the movement and patterns of prices with a larger sample and to understand some underlying causal factors for the observed differential price trend and price variation.

Scaling innovation like biofortification involves public sector governance, leadership and management, collaboration, and evidence learning in the seed system and value chain. Chapter three used Process Net-Map, field lab experiments which could not evaluate the policy aspect of biofortification. Further study on the scaling of biofortification could entail using the scaling readiness scan that incorporates the seed system and policy analysis. Secondly, the study provided insight into the effect of information provision on identifying iron beans using the field-lab experiment which is limited by sample size, selectivity bias and endogeneity. We recommend further studies on the subject using random control experiments or analysis involving quasi-experimental methods to complement the result of field lab experiments.

In chapter four, endogeneity was one of our study's limitations. Contracts may be correlated with the error term, which makes the estimates biased. Though we have used the CRE model, the model can only partially correct the correlation between contracts and the error term. In such cases, the results can be interpreted cautiously or as an association between contracts and outcomes instead of causal effects. Secondly, the mapping of the aggregators, processors and retailers may not be compressive due to limited resources, subsequently affecting the second and third-round survey sample size. A more robust study on the effect of contracts on aggregators, retailers, and processors would include a comprehensive listing of value chain actors and analysis that involves many outcomes.

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