



## **Commercialization of Papua New Guinea's Vegetable Sector:**

### **Identifying Constraints using Quantitative, Qualitative, and Large Language Model Methods**

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## ABSTRACT

This paper evaluates the constraints within Papua New Guinea's vegetable sector, drawing on large-scale household surveys, extensive qualitative interviews with key stakeholders, and Large Language Model (LLM) methods.

Our survey data reveal that vegetable production is ubiquitous, with almost all households surveyed (91%) growing at least one vegetable. Indigenous varieties, such as leafy greens (96%) and fresh beans (69%), are widely cultivated across regions, while high-value vegetables like onion (17%) and tomato (19%) show more regional concentration. Over half (53%) of PNG vegetable farmers sell their produce, with farmers located in the nonseasonal highlands agro-ecological area leading in market participation (66%), contributing to an overall commercialization rate of 24% (defined as the share of production sold). However, modern input use, particularly improved seed adoption, significantly lags behind output commercialization in all agroecological zones except the islands survey areas.

The quantitative analysis, using the PNG Rural Household Survey 2023, and the qualitative analysis, drawing from both manual review and LLM-assisted processing of in-depth interview notes, consistently identify poor feeder roads as critical bottlenecks for every stakeholder across PNG's vegetable value chain. Beyond transportation, these interviews repeatedly highlighted persistent seed supply shortages and high seed costs as significant hurdles. Since PNG depends on imported vegetable seeds, several structural and procedural barriers contribute to these shortages. These include potentially arduous quarantine procedures, limited foreign exchange for seed imports, and cumbersome permit processes, often leaving major distributors with insufficient stock. These reported bottlenecks may contribute to the low improved seed adoption and use reflected in the household survey analysis.

# 1. INTRODUCTION

The Papua New Guinea (PNG) government has prioritized transforming its agricultural sector from traditional subsistence farming to greater production specialization with strong market linkages (GoPNG, 2023). According to previous research, agricultural commercialization can increase farmer's incomes, as well as improve nutrition and child growth outcomes (Allen et al., 2005; Curry et al., 2019; Heywood and Hide, 1994; Songsermsawas et al., 2023).

While rural households in PNG earn substantial income from export cash crops like coconut, coffee, cocoa, and oil palm, the sales of fresh produce represent an even more widespread source of cash for many, playing an important role in their livelihood (Palaniappan et al., 2011; Sharp and Busse, 2020). Additionally, domestically oriented crops often serve as farmers' initial entry point into the market economy.

Consequently, the PNG government has identified diverse fresh vegetable value chains as an important avenue for promoting more diversified export cash crop opportunities (e.g., capsicum, onion, and brassicas) and for substituting imports (e.g., onion) (DAL, 2023). However, data and knowledge gaps exist regarding the comprehensive picture of vegetable commercialization and its associated bottlenecks. This paper aims to fill these gaps by identifying constraints within PNG's vegetable sector, drawing on a large-scale household survey, extensive qualitative interviews with key stakeholders, and large language model (LLM) methods.

Analysis based on the PNG Rural Household Survey 2023 (PNG-RHS 2023) reveals that vegetable production is ubiquitous. Almost all households surveyed (91%) grow at least one vegetable. Indigenous varieties, such as leafy greens (96%) and fresh beans (69%), are widely cultivated, while high-value vegetables like onion (17%) and tomato (19%) show more regional concentration. Over half (53%) of PNG vegetable farmers sell their produce, with the Non-seasonal Highlands agroecological zone leading in market participation (66%), contributing to an overall commercialization rate of 24% (defined as the share of production sold).

However, modern input use, particularly improved seed adoption, lags behind output commercialization in all agroecological zones except the islands area. Given that PNG largely depends on imported vegetable seeds, several structural and procedural barriers contribute to these shortages. These include potentially overly arduous quarantine procedures, limited foreign exchange for seed imports, and cumbersome permit processes, often leaving major distributors with insufficient seed stock.

We contribute to the literature in several ways. Previous research on agricultural commercialization typically focuses on either the output or input side. This paper examines both input adoption and output commercialization (e.g., market participation), two understudied dimensions within PNG's vegetable value chain. On the methodological front, we complement our quantitative analysis of smallholder farmers (using household survey data) with a qualitative analysis of midstream stakeholders. This qualitative data uses semi-structured key informant interviews to enable a holistic understanding of the constraints along the vegetable value chain in PNG. In analyzing the qualitative interviews, we use 2 methodologies to extract key messages: 1) manual data extraction and, 2) Large Language Model (LLM) data extraction. We find that both methodologies yield similar results, however parameter modification of the LLM model is necessary to ensure results are not lost during the automated data extraction process.

This paper is organized as follows: Section 2 reviews literature on current policies for agricultural commercialization in PNG and evaluates previous studies informing the fresh vegetable value chain. Section 3 describes the data and methodology. Section 4 presents quantitative analysis on vegetable crop choices, agricultural input use, and vegetable sales and commercialization rates across regions. Section 5 presents a qualitative analysis based on detailed interviews with mid-stream value chain stakeholders, comparing manual interpretation of compiled interview notes with outputs generated by LLMs to evaluate similarities and differences in results derived from in-depth qualitative data collection. Section 6 concludes with a discussion on policy implications and opportunities for improving vegetable commercialization in PNG.

## 2. LITERATURE REVIEW ON POLICIES AND FACTORS ASSOCIATED WITH AGRICULTURAL COMMERCIALIZATION

Promoting agricultural commercialization has been high on the agenda of the PNG government. As shown in Table 1, the government and international donors have developed a series of agricultural development plans for PNG over the past two decades, all with the goal of supporting agricultural commercialization. Despite its policy importance, research on agricultural commercialization in PNG has been rather limited. Literature on PNG’s vegetable value chains highlights persistent constraints and emerging opportunities in production and marketing, emphasizing the need to improve domestic fresh produce marketing systems (FPDA, 2008; Omot et al., 2007; Spriggs and Chambers, 2007).

**Table 1: Key National Policies and Projects Supporting Agricultural Commercialization in PNG**

Policy/Project Name	Years	Goals	Key Activities
<b>National Agriculture Development Plan</b> (GoPNG, 2007)	2007–2016	<ul style="list-style-type: none"> <li>- Increase agricultural productivity and commercialization</li> <li>- Improve rural income and employment</li> </ul>	<ul style="list-style-type: none"> <li>- Develop market-oriented production and marketing systems</li> <li>- Facilitate downstream processing and value-adding activities</li> <li>- Support nucleus estates, out-grower schemes, and cooperatives</li> <li>- Enhance farmer access to credit, inputs, and market infrastructure</li> </ul>
<b>Agriculture Medium Term Development Plan</b> (GoPNG, 2020)	2020–2022	<ul style="list-style-type: none"> <li>- Develop a world-class agriculture sector responsive to markets</li> <li>- Increase revenue, exports, and reduce imports</li> </ul>	<ul style="list-style-type: none"> <li>- Improve market-oriented infrastructure (roads, ports, airstrips)</li> <li>- Promote downstream processing and value addition</li> <li>- Facilitate public-private partnerships and investments</li> </ul>
<b>Productive Partnerships in Agriculture Project</b> (DAL et al., 2011)	2010–2021	<ul style="list-style-type: none"> <li>Improve smallholder livelihoods via enhanced cocoa and coffee commercialization.</li> </ul>	<ul style="list-style-type: none"> <li>- Form productive partnerships linking farmers to markets.</li> <li>- Provide infrastructure and training to boost market-oriented production.</li> </ul>

<b>PNG Agriculture Commercialization and Diversification</b> (World Bank, 2020)	2020–2025	Develop competitive and diversified agricultural value chains	<ul style="list-style-type: none"> <li>- Rehabilitate feeder roads for market access.</li> <li>- Facilitate partnerships for aggregation, processing, and marketing.</li> </ul>
<b>Market for Village Farmers (MVF) Project</b> (IFAD, 2024)	2018–2026	Transition smallholders from subsistence to market-oriented farming; increase marketed surplus	<ul style="list-style-type: none"> <li>- Establish business partnerships with lead partners to support production, aggregation, and marketing</li> <li>- Support bankable business plans and matching grants for infrastructure, inputs, and processing</li> </ul>
<b>National Agriculture Sector Plan</b> (GoPNG, 2023)	2024–2033	<ul style="list-style-type: none"> <li>- Transform agriculture from subsistence to commercial enterprise</li> <li>- Increase production for downstream processing and exports</li> </ul>	<ul style="list-style-type: none"> <li>- Support large-scale crop/livestock commercial farming and agri-industrial centers in each province</li> <li>- Promote downstream processing and value addition through MSMEs/MSMIs</li> <li>- Mobilize public-private investment and build infrastructure for processing and market access</li> </ul>

**Source:** Summarized by authors based on the policy/program documents.

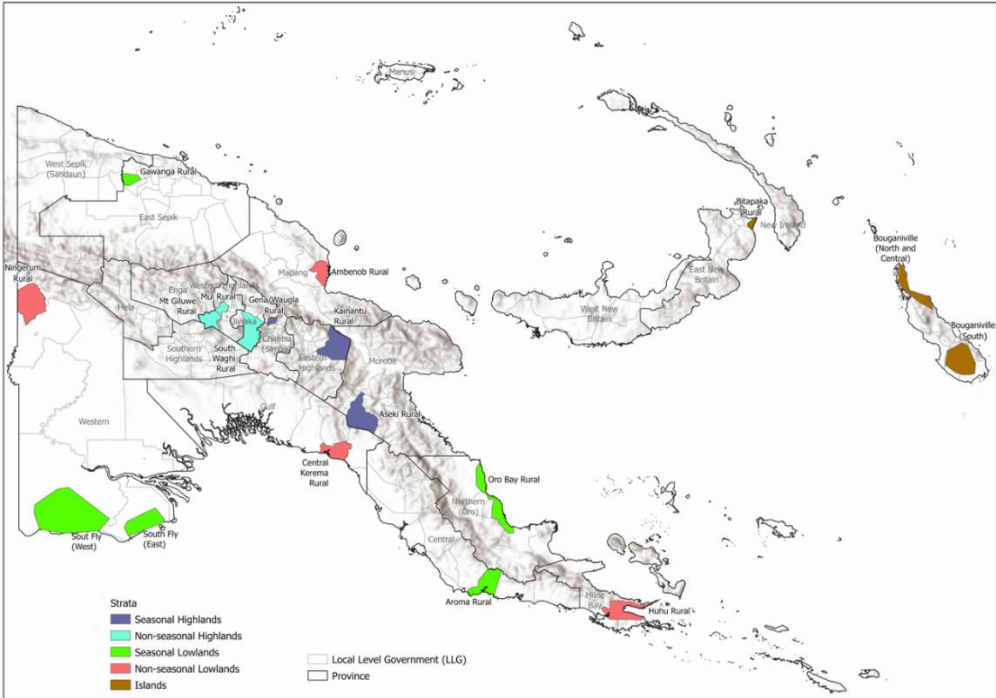
Access to markets and transportation infrastructure have been identified as key factors for agricultural commercialization and associated input adoption in many developing countries. This holds true for both commercial output sales (Agwu et al., 2013; Dube and Guveya, 2016; Pender and Alemu, 2007; Tafesse et al., 2020; Tufa et al., 2014) and the adoption of commercial inputs (Zerfu and Larson, 2010). Minten et al., (2013) examined the effects of the "last mile" in input access, finding that traveling 10 kilometers to acquire inputs doubled the input price. However, for more remote producers (characteristic of PNG rural landscape), other studies revealed that traders can play an important role in efficiently distributing modern seed varieties for both formal and informal market actors (McGuire and Sperling, 2016; Sperling and Almekinders, 2023).

### 3. METHODOLOGY AND DATA

We used the PNG Rural Household Survey 2023 (PNG-RHS 2023), as well as a series of qualitative interviews with various stakeholders along the vegetable value chain to explore the challenges and opportunities for vegetable value chain commercialization.

The PNG-RHS 2023 collected comprehensive household-level data on agricultural production, food and non-food consumption and expenditure, and livelihood strategies across 14 provinces, covering communities in the highlands, lowlands, and islands of PNG (Figure 1). We present analysis by five agroecological zones (Seasonal Highlands, Non-seasonal Highlands, Seasonal Lowlands, Non-seasonal Lowlands, and Islands) to highlight regional variations in vegetable value chain commercialization. Although the PNG-RHS is not nationally representative, it is the most recent survey to gather detailed agricultural production and marketing information, including input use (the last nationally representative survey on agriculture production was the agriculture census conducted in 1961/62). The survey employed a purposive sampling strategy based on defined agroecological zones, which allows for the analysis of key factors influencing rural households and communities. It encompasses 2,699 households in 270 communities, of which 2,444 of those households grow vegetables, making this survey well-suited to study the producer component of PNG's vegetable value chain.

**Figure 1: 2023 PNG Rural Household Survey sample selection**



**Source:** PNG Rural 2023 Household Survey

To explore the off-farm components of the vegetable value chain, we conducted 29 in-depth, key informant interviews with lead farmers, aggregators, seed suppliers, and transporters between October and November 2023. We gathered information on production decisions, input use, transportation, and marketing through semi-structured interviews.

Using data from the PNG-RHS 2023 survey, we first present descriptive statistics to understand vegetable cultivation, input use, and output sales (commercialization) in rural PNG. Commercialization is typically associated with a high degree of production concentration or specialization. To explore how diverse vegetable production may be specializing to benefit from economies of scale, we calculate the Hirschman–Herfindahl Index (HHI) to measure the degree of concentration by vegetable type. The HHI is calculated by squaring the share of each crop in the total land area and then summing the resulting values (on a scale from 0 to 1). A larger HHI indicates greater concentration in production.

Recognizing the nuanced nature of decisions to invest in the commercialized vegetable market, we pair the quantitative analysis with in-depth key informant interview data. We analyze these qualitative data using both manual categorization of key topics and messages, and LLMs.

## 4. DESCRIPTIVE RESULTS

### 4.1 Crop choice of fresh vegetables

Of the 2,699 surveyed households, 91% (2,444 households) planted at least one type of vegetable. On average, surveyed households operated approximately 1.58 hectares of agricultural land (Schmidt et

al., 2024). Indigenous vegetables, particularly leafy greens<sup>1</sup> (grown by 96% of vegetable farmers) and fresh beans (69%), were the most widely cultivated crops across agroecological zones. While non-indigenous vegetables are less commonly grown among rural farming households, onion (17%) and tomato (19%) were relatively more commonly cultivated than other commercial vegetables (eggplant, capsicum, and cabbage) (Table 2). Onion was predominantly grown in the Highlands and Islands but was rare in the Lowlands, whereas tomato was more common in the Islands and the Highlands.

To further examine these patterns, we calculated the Hirschman–Herfindahl Index (HHI) to evaluate the concentration of vegetable production across agroecological zones. The HHIs for indigenous vegetables were relatively low, consistent with their widespread cultivation for home consumption across regions. Conversely, all high-value non-indigenous vegetables—including onion, tomato, eggplant, capsicum, and cabbage—exhibited HHIs greater than 0.25, indicating a higher degree of regional concentration. For instance, the HHI for the two most common commercial vegetables, onion and tomato, is as high as 0.32 and 0.35, respectively, indicating that commercial vegetable production has become specialized based on regional comparative advantages.

**Table 2: Share of vegetable-growers growing vegetables by agroecological zone**

	All sample	Seasonal Highlands	Non-seasonal Highlands	Seasonal Lowlands	Non-seasonal Lowlands	Islands	HHI
<b>Leafy Greens</b>	96	97	91	95	98	97	0.20
<b>Fresh beans</b>	69	74	75	70	61	68	0.20
<b>Squash/Pumpkin</b>	55	64	39	73	59	27	0.22
<b>Pitpit</b>	13	13	5	14	21	8	0.24
<b>Onion</b>	17	26	21	7	0	42	0.32
<b>Tomato</b>	19	10	5	18	13	51	0.35
<b>Cucumber</b>	9	7	3	10	14	7	0.24
<b>Eggplant</b>	8	0	0	6	6	28	0.53
<b>Capsicum</b>	4	4	0	0	0	21	0.72
<b>Cabbage</b>	3	3	10	0	0	2	0.47
<b>No. of vegetable growers</b>	2444	419	424	656	528	417	

Source: PNG Rural 2023 Household Survey

Notes: HHI = Herfindahl–Hirschman index. Indigenous vegetables include leafy greens, fresh beans, squash/pumpkin, and pitpit. The others are non-indigenous.

## 4.2 Vegetable commercialization: modern input use versus market sales

The PNG-RHS reveals that the adoption of modern agricultural inputs among vegetable farmers within the survey remains relatively low. It is important to note, however, that the PNG-RHS includes a large share of relatively remote households with limited market access, which may partly explain the low

<sup>1</sup> As it is difficult for the respondents to distinguish specific green leafy vegetables, we aggregated them as one group (i.e. "leafy greens"), and we did the same for fresh beans.

overall reported modern input use and commercial vegetable sales. Overall, only 8.2% of surveyed vegetable farmers used agrochemicals, 4.7% used inorganic fertilizers, and 4.5% used organic fertilizers (Appendix Table A1). However, fertilizer use varies by region. For example, 21% of vegetable farmers in the Non-Seasonal Highlands sample that supplies Mt. Hagen and Goroka markets (i.e., Western Highlands, Chimbu, and Jiwaka provinces) apply inorganic fertilizers, whereas usage is nearly absent in the Lowlands and Islands agro-ecological zones survey sample.

The adoption of improved seeds among the PNG-RHS sample is also limited. Appendix Table A2 presents the share of vegetable growers adopting improved seed by vegetable type. High-value vegetables such as onion (14%), tomato (13%), eggplant (19%), and capsicum (40%) have higher improved seed adoption rates than indigenous vegetables, whose usage ranges between 3–9%.<sup>2</sup>

Farmers in the Non-seasonal Highlands and Islands survey areas demonstrate higher adoption rates of improved seeds than the other agroecological zones for both traditional and non-traditional vegetables. For example, about 20 percent of the onion farmers in the Non-seasonal Highlands adopted improved seed, respectively, consistent with the high concentration of onion production in this area.

We use two metrics to assess vegetable farmers' market participation: the proportion of growers engaged in vegetable sales and the share of total vegetable production sold. Appendix Table A3 presents the share of vegetable growers engaging in sales among PNG-RHS sampled farmers. Overall, 53% of surveyed vegetable growers reported selling their produce, with the highest share observed in the Non-seasonal Highlands (66%), followed by the Seasonal Highlands (57%). These figures suggest that farmers in the Highlands are more likely to generate surplus vegetables for market sales compared to those in other regions of PNG. Among the major vegetables, approximately two-thirds of the fresh bean, leafy green, onion, and tomato growers in the Non-seasonal Highlands reported participating in sales. Leafy greens and fresh beans exhibited the highest overall rates of participation, with 49% and 42% of growers selling their produce, respectively.

Appendix Table A4 presents vegetable commercialization rates (measured as the share of production sold) by vegetable type and agroecological zone.<sup>3</sup> Overall, an estimated 17% of vegetable production was sold. The Non-seasonal Highlands exhibited the highest commercialization rate, with approximately a quarter of the vegetable production sold. While a high share (57%) of vegetable growers in the Seasonal Highlands engaged in sales (extensive participation), the proportion of production sold was minimal (low intensive participation), indicating that many smallholders sold only minor shares of their overall production. In contrast, growers in the Non-seasonal Highlands demonstrated both extensive and intensive market engagement. For example, two-thirds of the onion growers in the Non-seasonal Highlands sold to the market, and about 37% of their total production was sold. These findings align with earlier results, suggesting that the Non-seasonal Highlands are the most commercialized region in terms of both commercial input use and output sales.

From an international perspective, PNG lags behind comparable developing economies in both commercial input adoption and output commercialization. For instance, while 21% of vegetable farmers in the most commercialized area of PNG (nonseasonal highlands) use inorganic fertilizer on their plots, approximately 80% of farmers in Myanmar use inorganic fertilizers (MAPSA, 2022). Improved seed adoption rates among vegetable farmers range between 30–50% across in Vietnam, Thailand, and the

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<sup>2</sup> Since only 113 farmers sampled grew capsicum, mostly in the Islands, the results regarding capsicum should be used with caution.

<sup>3</sup> The commercialization rate is defined by dividing the land area allocated to vegetable production for sales by the total land area of vegetable production, as estimating total production value is challenging in PNG.

Philippines (ReportLinker, 2023), compared to 14–40% among vegetable farmers in PNG. PNG's output commercialization also trails behind. In Southeast Asia, for example, Myanmar's vegetable commercialization rate is over 90% (MAPSA, 2022).

Figure 2 presents radar charts illustrating the use of modern inputs and the extent of output sales for four major vegetables: leafy greens, fresh beans, tomatoes, and onions. The central red dots signify zero input use or output sales. Each of the four crops extends outward from the center in different directions, with the distance from the center reflecting the level of input use or output commercialization: the farther a point is from the center, the higher the value and the greater the commercialization. The figure helps visualize the relative performance of commercialization on both the input and output sides.

The area enclosed by the four points on the radar chart represents the overall level of input use or output commercialization for the four vegetables. For example, focusing on the full sample graph, the four vertices of the teal shape show that the commercialization rates for the four vegetables are all close to 20%. The area of this teal shape represents the aggregate level of output commercialization. The orange area, representing the input use of the four vegetables, is significantly smaller than the output (teal) areas, suggesting that input commercialization lags behind output commercialization. This sluggish commercialization of inputs might impede the commercialization of outputs. However, regional disparities are evident. For example, the Islands region is the only area that has a greater share of producers buying and using commercial inputs compared to selling agricultural output. Additionally, vegetable farmers in both the Non-seasonal Highlands and Islands are more commercialized than those in other regions, as indicated by their larger enclosed areas on the charts. Conversely, input use in the Non-seasonal Lowlands is almost non-existent for the four vegetables graphed in Figure 2 (and onions are not sold among households in Non-seasonal Lowlands sample).

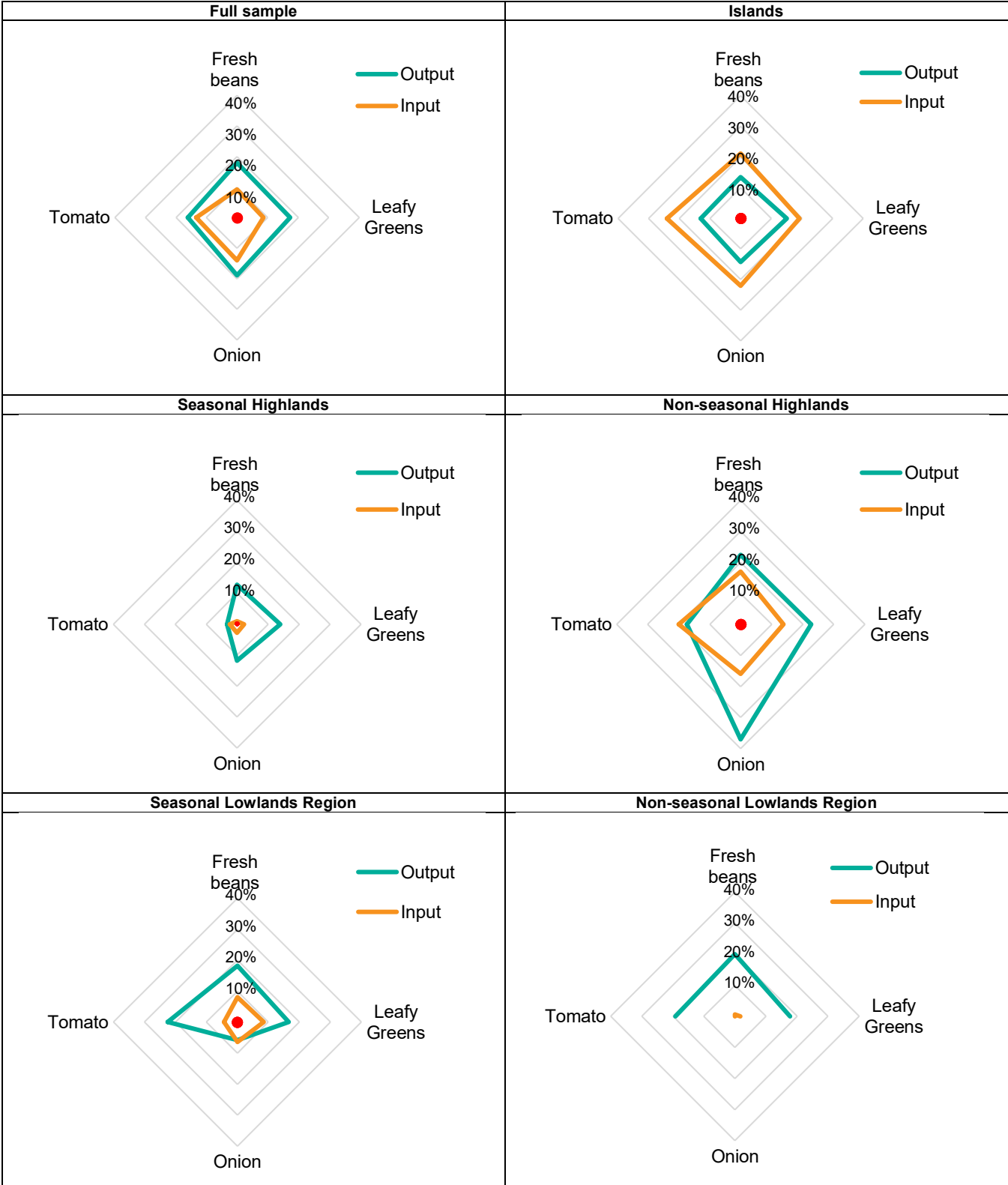
Table 3 reports t-test results, which show that vegetable farmers who used improved seeds were more likely to participate in vegetable sales and sold a larger share of their production.

**Table 3: T-tests on the share of households selling vegetables and share of vegetable production that is sold**

	Any vegetable		Onion		Tomato		Leafy Greens		Fresh beans						
	Used imp. seed		Used imp. seed		Used imp. seed		Used imp. seed		Used imp. seed						
	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes					
<b>Share of HH selling</b>	52	65	***	37	39	31	30	49	56	*	42	51	**		
<b>Share of production sold</b>	15	23	***	16	23	*	14	19	*	17	25	***	16	22	***

Source: PNG Rural 2023 Household Survey

**Figure 2: Visualization of modern input use and output sales of major vegetable farmers by agroecological zone**



Source: 2023 PNG Rural Household Survey.

Note: 1) We use only the share of improved seed use for the input because the agrochemical data is available only at the plot level rather than the crop level, while commercialization rate is used to represent output. 2) Onion in the Non-seasonal Lowlands Region was excluded because there are only 2 onion growers.

## 5. COMPLEMENTARY EVIDENCE FROM QUALITATIVE INTERVIEWS WITH OFF-FARM STAKEHOLDERS

While our quantitative analysis focuses on rural vegetable smallholders (the on-farm component of the vegetable value chain), we complement this with qualitative insights from interviews conducted with midstream (off-farm) stakeholders, including lead farmers, aggregators, traders, and transporters. These intermediaries play a critical role in bridging rural production and urban demand. They also move goods between rural producers and larger buyers, such as mining operations in PNG's interior and exporters and importers at PNG's ports. Although PNG marketplaces traditionally feature a larger share of producer/farmer involvement and limited development of trade intermediaries (Sharp and Busse, 2020), interviews for this study suggested a recent increase in midstream actors in the vegetable value chain.

Our qualitative analysis focused on the onion value chain along the Highlands highway (a key production area for fresh vegetables). Of the 29 in-depth interviews conducted there, 26 were conducted in the Western Highlands Province and Eastern Highlands Province. Our interviewees included 16 lead farmers (who both produce and facilitate for smaller farmers), 6 aggregators (who consolidate and sell produce to traders and other buyers), 3 input suppliers, and 1 transporter.

All stakeholder interviews were transcribed and are provided in a supplementary document with interview respondent names replaced to preserve anonymity. We first manually combed through the transcribed interviews to identify common answers to input and output constraint questions within interviewee occupations (e.g., lead farmer, aggregator, input supplier), as well as across interviewee occupations.

A manual review of the interview notes revealed that access to improved seed and transportation issues were the two most frequently reported challenges. Specifically, 14 of the 16 lead farmers highlighted seed-related issues, including seed supply shortage and high cost, as an important challenge (Table 4). Seed suppliers echoed farmers' perceptions, explaining that heavy reliance on imports led to these shortages. During discussions about transportation challenges, lead farmers, aggregators, and transporters reported issues with poor feeder road conditions, high transportation costs, delays due to the unavailability of vehicles, and vehicle breakdowns.

We also used LLMs as a secondary analysis source to identify common bottlenecks to fresh vegetable value chain function. In doing so, we test the LLM ability to identify similar results from the manual evaluation of key topics identified during the in-depth qualitative interviews. For the LLM analysis, we focus on a specific question to employ two recent AI models (GPT-o3 and GPT-4o)<sup>4</sup> to analyze our detailed interview notes using a consistent prompt: "Based on all the files, how many interviews reported any issues/constraints/challenges regarding seed, both explicitly and implicitly? Please provide references/evidence."

We evaluated the same set of transcribed interviews using both the GPT-o3 and GPT-4o models. Each model's analysis was run ten times, with its memory cleared before each new round. According to OpenAI's descriptions, GPT-4o is designed for high performance across a broad range of tasks and is generally considered "great for most questions." However, in our application, it generated inconsistent responses, achieving only about 50% accuracy in some instances when identifying the seed-related constraint compared to the manual evaluation (Table 4).

On the other hand, the GPT-o3 model, which OpenAI notes for its solid reasoning capabilities, generated more consistent responses, achieving about 96% accuracy compared to the manual evaluation.

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<sup>4</sup> According to OpenAI (2024), the "GPT-4o" model performs well across a wide range of tasks, while the "GPT-o3" model is optimized for advanced reasoning capabilities.

For example, similar to the manual evaluation, the GPT-o3 model<sup>5</sup> emphasized that the farmer in Interview No. 15 reported conducting "repeated trips from home to town for almost 15 times in a month to check seed availability." However, it's important to note that the GPT-o3 model also included one false positive case based on our manual verification.<sup>6</sup>

Similar to the findings on seed-related constraints, the GPT-o3 demonstrated a more accurate and consistent response than the GPT-4o in identifying transportation-related constraints. In line with the manual analysis, GPT-o3 recognized that all interviewees, including lead farmers, aggregators, and the transporter, highlighted transportation as a major constraint. For instance, the aggregator in Interview No. 17 reported that poor feeder road conditions make it extremely difficult to transport vegetables from her contact farmers to her facility, jeopardizing the consistency of supply to her clients. Similarly, the aggregator in Interview No. 18 noted the challenges associated with sea shipping, reporting that four aggregators near his village had gone out of business due to significant vegetable losses during transport. Nearly all lead farmers and the transporter expressed concerns about poor road conditions, particularly during the rainy season.

**Table 4: Comparison of ChatGPT Model Variants in Identifying Seed- and Transportation-related Constraints from Detailed Interview Notes**

	Total interviews	Manual search	ChatGPT "4o"		ChatGPT "o3"		ChatGPT "o3" with "Deep research"	
			Total w/ issues	Accuracy	Total w/ issues	Accuracy	Total w/ issues	Accuracy
<b>Seed-related constraints</b>	<b>25</b>	<b>23</b>	<b>12~22</b>	<b>52.2%~95.7%</b>	<b>22</b>	<b>95.7%</b>	<b>23</b>	<b>100%</b>
Lead farmers	16	14	7~13	50.0%~92.9%	13	92.9%	14	100%
Aggregators	6	6	4~6	66.7%~100%	6	100%	6	100%
Input Suppliers	3	3	1~3	33.3%~100%	3	100%	3	100%
<b>Transportation-related constraints</b>	<b>23</b>	<b>23</b>	<b>14~21</b>	<b>60.9%~91.3%</b>	<b>22~23</b>	<b>95.7%~100%</b>	<b>23</b>	<b>100%</b>
Lead farmers	16	16	8~14	50.0%~87.5%	16	100%	16	100%
Aggregators	6	6	4~6	66.7%~100%	5~6	83.3%	6	100%
Transporter	1	1	1	100%	1	100%	1	100%

**Source:** Authors' qualitative interviews with the midstream stakeholders in the vegetable value chain in October and November 2023 in the Highlands of PNG.

**Notes:** 1) The authors have conducted a comprehensive review of all interview transcripts. Given our familiarity with the content, we are confident that the manual search has effectively captured all interviews referencing seed-related or transportation-related constraints. 2) The interview with the transporter did not include any questions related to seeds; therefore, the first panel on "seed-related constraints" excludes the transporter. Similarly, the interviews with input suppliers did not cover transportation issues, as these suppliers are typically large companies equipped with their own transportation infrastructure and are unlikely to face such constraints. As a result, the second panel on "transportation-related constraints" excludes the input suppliers.

<sup>5</sup> ChatGPT also offers a non-free "Deep Research" mode, designed for more in-depth analysis, which took approximately 10 to 20 minutes to analyze our detailed interview notes. The GPT-o3 model with the "Deep Research" option achieved 100% accuracy in identifying all interviews that reported seed-related constraints. The detailed output from ChatGPT is available in Appendix LLM results B1-B6.

<sup>6</sup> The interviewee of the Interview 5, who is a trader, mentioned that he provides seeds to his contact farmers. ChatGPT "o3" interpreted this as evidence of a seed shortage, but this appears to be a false positive inference.

## 6. DISCUSSION AND CONCLUSION

Previous research in South Asia and the Pacific has shown that investing in vegetable commercialization can improve employment, food security, nutrition, and rural livelihoods (Balayar and Mazur, 2022; Kelly, 2019; Pandey et al., 2022; Songsermsawas et al., 2023). Yet, studies on vegetable commercialization are scant in the Pacific. This study begins to fill a gap in the knowledge by combining recently collected rural household survey data on agricultural production and farmer decision-making with in-depth key informant interviews of mid-stream value chain actors.

Focusing on the survey data analysis, we found that almost all surveyed rural households (91%) grow at least one vegetable. Indigenous vegetables, such as leafy greens (96%) and fresh beans (69%), are widely produced across different agroecological zones. By comparison, high-value vegetables like onion and tomato are more regionally concentrated.

More than half (53%) of PNG vegetable farmers sell their produce, with the Non-seasonal Highlands (66%) showing the highest market participation and a 24% overall commercialization rate (defined by the share of production sold). Modern input use among vegetable farmers in PNG is less common, regardless of whether production is commercially oriented. Overall, only 8.2% of surveyed households reported using agrochemicals, though regional variations in input use exist. Improved seed adoption among survey households is also limited but relatively more common for high-value crops like onion (14%). Improved seed adoption significantly lags behind output commercialization in all agroecological zones, except the Islands, which may hinder further market expansion.

Given the importance of modern inputs for the commercialization of PNG's vegetable value chain, we explored structural constraints in seed access by comparing PNG's seed imports with those of nearby countries, as imports are the main source of vegetable seeds for PNG (Seta-Waken et al., 2017). Appendix Table A5 compares the composition of sourcing countries and the average price of vegetable seeds imported between 2002 and 2021. Approximately 96% of the value of seed imported to PNG, between 2002 and 2021, were purchased from three countries. Half of the value of seed imports originated from Japan. In contrast, other nearby countries have more diversified sources. For example, 97% of the value of seed imports in Fiji are purchased from seven countries, paying only about 15% of the price that PNG paid for seeds. French Polynesia, which imported a comparable quantity of vegetable seeds to PNG (134 tons versus 111 tons), paid approximately 60% of PNG's price (56 \$/kg versus 93 \$/kg). Samoa imported only one-third the quantity of vegetable seeds that PNG imported (35 tons versus 111 tons), however paid about 20% of PNG's price (20 \$/kg versus 93 \$/kg). Both PNG and Solomon Islands incurred significantly higher prices on imported vegetable seed than their regional peers. This suggests that diversifying import sources could reduce costs.

Further barriers may stem from systemic inefficiencies, which could be further evaluated to ease seed imports. Wiles and Mwayawa (2001) raised concern over lengthy quarantine procedures for the import of vegetable seeds. The National Agricultural Development Plan 2007-16 (MoAL, 2005) indicated that import permits for improved seeds were issued on a consignment basis by NAQIA. Such policies may lead to major distributors of vegetable seeds struggling to maintain adequate seed inventories.

Streamlining border clearance protocols and revising import permit systems could alleviate immediate bottlenecks. Additionally, the government may consider sourcing vegetable seeds from additional origins by negotiating trade agreements and partnerships with new countries. This may help mitigate biosecurity risks and ensure compensation in case of biosecurity issues. Beyond legal regulations, robust

lab and field testing, along with thorough inspections, are crucial for addressing biosecurity concerns effectively.

Both our quantitative and qualitative analyses identify transportation-related constraints as a critical bottleneck for every stakeholder across PNG's vegetable value chain. These include poor feeder roads and limited availability of Public Motor Vehicles (PMVs) to transport goods to market. While long-term government investment in infrastructure remains essential, short-term and low-cost interventions could offer immediate improvements. For example, according to an infrastructure expert currently involved in maintaining the Highlands highway, building and maintaining feeder roads using river stones is a practical, cost-effective solution that leverages local materials.

Although PMVs offer high capacity, their limited availability in rural areas is a major barrier to rural accessibility. A potential affordable alternative to evaluate could be a motor tricycle, which is common in South Asia, Southeast Asia, and Africa. Their adaptability to narrow and unpaved roads may be particularly suitable for PNG's rural commercial farmers to transport vegetables to aggregator depot areas.

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# APPENDIX

## Appendix tables

**Table A1:** Share of vegetable growers using fertilizers and agrochemicals by agroecological zone

	All sample	Seasonal Highlands	Non-seasonal Highlands	Seasonal Lowlands	Non-seasonal Lowlands	Islands
Compost	3.0	2.9	6.8	2.9	1.7	1.0
Manure	2.5	3.3	8.3	0.2	0.8	1.9
<b>Any organic fertilizer</b>	<b>4.5</b>	<b>4.5</b>	<b>11.1</b>	<b>3.0</b>	<b>2.3</b>	<b>2.9</b>
Lime	0.9	0.2	3.5	0.2	0.8	0.0
Inorganic fertilizers	4.7	4.1	21.2	0.2	0.8	1.0
Pesticides/fungicides	2.1	1.7	3.3	0.2	3.4	2.9
Herbicides	2.0	3.8	4.5	0.2	0.2	2.9
<b>Any agrochemical</b>	<b>8.2</b>	<b>8.8</b>	<b>25.7</b>	<b>0.6</b>	<b>5.1</b>	<b>5.5</b>
<i>No. of vegetable growers</i>	<i>2444</i>	<i>419</i>	<i>424</i>	<i>656</i>	<i>528</i>	<i>417</i>

Source: PNG Rural 2023 Household Survey

**Table A2:** Share of vegetable growers adopting improved seed by crop by agroecological zone

	All sample	Seasonal Highlands	Non-seasonal Highlands	Seasonal Lowlands	Non-seasonal Lowlands	Islands
<b>Leafy Greens</b>	9	2	14	8	2	19
<i>N</i>	<i>2351</i>	<i>407</i>	<i>393</i>	<i>625</i>	<i>520</i>	<i>406</i>
<b>Fresh beans</b>	9	1	17	8	1	21
<i>N</i>	<i>1691</i>	<i>309</i>	<i>317</i>	<i>458</i>	<i>323</i>	<i>284</i>
<b>Squash/Pumpkin</b>	5	1	10	6	0	16
<i>N</i>	<i>1340</i>	<i>267</i>	<i>164</i>	<i>480</i>	<i>315</i>	<i>114</i>
<b>Pitpit</b>	3	6	0	2	1	15
<i>N</i>	<i>317</i>	<i>54</i>	<i>23</i>	<i>95</i>	<i>111</i>	<i>34</i>
<b>Onion</b>	14	3	16	6	0	22
<i>N</i>	<i>422</i>	<i>108</i>	<i>88</i>	<i>47</i>	<i>2</i>	<i>177</i>
<b>Tomato</b>	13	2	20	4	0	24
<i>N</i>	<i>456</i>	<i>42</i>	<i>20</i>	<i>116</i>	<i>66</i>	<i>212</i>

<b>Cucumber</b>	10	0	25	17	4	13
<b>N</b>	212	29	12	65	75	31
<b>Eggplant</b>	19	0	0	12	3	26
<b>N</b>	191	0	0	42	32	117
<b>Capsicum</b>	40	22	0	100	0	43
<b>N</b>	113	18	1	1	1	92

Source: PNG Rural 2023 Household Survey

**Table A3:** Share of vegetable growers making sales, by crop and agroecological zone

	Fresh beans	Leafy Greens	Squash/ Pumpkin	Pitpit	Onion	Tomato	Cucumber	Eggplant	Capsicum	Any vegetable
<b>All sample</b>	42	49	33	32	38	31	43	31	35	53
<b>Seasonal Highlands</b>	41	53	24	22	32	14	45	0	67	57
<b>Non-seasonal Highlands</b>	59	59	47	96	67	65	33	0	100	66
<b>Seasonal Lowlands</b>	45	51	38	47	27	37	49	50	0	54
<b>Non-seasonal Lowlands</b>	37	45	29	13	33	39	45	22	100	47
<b>Islands</b>	27	38	25	21	29	25	29	27	27	40
<i>Number of sellers</i>	714	1153	443	100	159	140	92	60	39	1290
<i>Number of growers</i>	1693	2349	1340	317	424	456	212	191	113	2444

Source: 2023 PNG Rural Household Survey

**Table A4:** Share of land allocated to vegetable production that goes towards sales (commercialization rate)

	Fresh beans	Leafy Greens	Squash/ Pumpkin	Pit-pit	Onion	Tomato	Cucumber	Egg-plant	Capsicum	All vegetables
<b>All sample</b>	18	17	13	12	19	16	19	13	22	17
<b>Seasonal Highlands</b>	13	14	5	12	12	3	16	0	49	12
<b>Non-seasonal Highlands</b>	22	23	21	36	37	17	23	0	88	24
<b>Seasonal Lowlands</b>	18	17	14	9	6	23	14	13	0	17

<b>Non-seasonal Lowlands</b>	20	18	17	5	49	19	27	15	75	19
<b>Islands</b>	18	17	13	12	19	16	19	13	22	17

Source: 2023 PNG Rural Household Survey.

Note: 1) The survey asked for the total size of a garden with multiple crops, but did not ask the size of each crop, so we assume the crops share the garden area evenly. 2) The survey did not the production and sale value of each crop. To calculate the aggregated share of vegetables that was sold, we assumed the land productivity of different vegetables the same.

**Table A5:** Share of vegetable seeds import by exporting country origin in total importing value of PNG and nearby countries between 2002 and 2021

Exporting countries/ areas	Indonesia	Philippines	Malaysia	New Caledonia	Fiji	PNG	French Polynesia	Vanuatu	Samoa	Solomon Islands
Australia				20	9	32	7	42	14	50
China			41						8	
France				32			25			
Hong Kong					33					
Indonesia			6							
Japan	20	23		12	11	50	11		23	
South Korea	9									
Taiwan					16		13			16
Netherlands		6	11	8			9			
New Zealand				20	6	14	15	48	43	19
India					9					
Singapore	27									
South Africa		11								
Thailand	22	21	15							8
USA		16			13		9			
Others	21	22	27	9	3	4	12	10	12	7
<b>Total</b>	100	100	100	100	100	100	100	100	100	100
<b>Total import (million \$)</b>	273	239	202	12	10	10	7	2	1	0.4

<b>Total quantity (tons)</b>	16,217	10,936	23,609	169	724	<b>111</b>	134	62	35	4
<b>Price (\$/kg)</b>	<b>17</b>	<b>22</b>	<b>9</b>	<b>73</b>	<b>14</b>	<b>93</b>	<b>56</b>	<b>31</b>	<b>20</b>	<b>101</b>
<b>GDP per capita (\$)</b>	4,731	3,548	11,748	33,516	5,405	<b>3,102</b>	20,739	3,265	3,869	2,005
<b>Ag GDP (\$)</b>	587	339	1,052		687	<b>524</b>			387	677
<b>Crop land (000' ha)</b>	45,389	11,183	8,285	10	139	<b>1,215</b>	29	145	43	112

Source: BACI trade dataset 2024.

## Appendix LLM results

### *B1. ChatGPT-4o's Normal Search on Seed-related issues:*

Prompt: "Based on all the files, how many interviews reported any issues/constraints/challenges regarding seed, both explicitly and implicitly? Please provide references/evidence."

The following is a response generated by ChatGPT in GPT-4o mode, which identified a relatively limited number of interviews referencing seed-related constraints:

- ◆ Lead Farmers (7 interviews)

Interview 1: Oct 25 – Terry

"He cites weather shocks, seed shortage and reliable transportation as major issues in procuring vegetables from farmers as it disrupts the production."

Interview 4: Oct 25 – Ethan

"Half of the seed that Ethan used is from farm saved seed, and the other half is purchased from input shops. The closest input shop for him is the Farmset in Kainantu, but the seed there is out-of-stock in more than half of Ethan's visits... he would need to go to Goroka or Lae."

Interview 6: Oct 25 – Alex

"His fellow farmers... do not have enough money to buy seeds."

Interview 12: Oct 27 – Jo

"He purchases seeds from Brianbell and Chemica in Goroka... the seed stock runs out quickly... seeds from other stores are higher in price."

Interview 14: Oct 28 – Karl

"He purchases his seeds from Brianbell... When the seed stock runs out, he patiently waits... high demand in stores around Goroka."

Interview 15: Oct 30 – Frank

"He has tried seeds from Asian stores, but the germination rate... is only about 60%... a lack of a steady seed supply poses a significant challenge... visited the shop 15 times a month."

Interview 16: Oct 30 – Jason

"Encountering a lack of seed stock in the shops is a common issue... he typically waits for 1-2 months... visits each week to see if seeds are available... spends 5 Kina one way."

- ◆ Aggregators (2 interviews)

Interview 3: Oct 25 – SUN, Allen

"Sustaining the business relationship [with a client] became challenging due to SUN's inconsistent supply, primarily stemming from seed constraints... persistent seed constraints."

Interview 4: Oct 30 – Hello Fresh (Talent)

"Talent... imports seeds and chemicals... However, their seed supply tends to deplete quickly, impacting local farmers' production."

## ***B2. ChatGPT-o3's Normal Search on Seed-related issues:***

Prompt: "Based on all the files, how many interviews reported any issues/constraints/challenges regarding seed, both explicitly and implicitly? Please provide references/evidence."

The following is a response generated by ChatGPT in GPT-o3 mode:

1. Lead Farmers.pdf

Total Interviews: 16

Interviews reporting seed-related issues: 14 out of 16 (**Upon manual verification, only 13 interviews contain relevant content. The inclusion of Interview 5 (Bob) by ChatGPT in o3 mode was a false positive.**)

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Interviews with Explicit Seed Issues

1. Terry (Interview 1)
  - o Reports "seed shortage" as a major problem in vegetable procurement.
2. Bob and Sam (Interview 2)
  - o Experienced 3–4 months of delays in getting seeds from Farmset and Brian Bell.
3. Dyson (Interview 3)

- o Describes frequent stockouts at Farmset and high seed prices; sometimes can't get desired seed even in Goroka.
4. Ethan (Interview 4)
    - o States that over 50% of visits to Farmset result in seed unavailability. Uses farm-saved seeds as backup.
  5. George (Interview 7)
    - o Notes seeds from small retailers are expensive; uses small potatoes as seed due to lack of access.
  6. Grace (Interview 9)
    - o Her farmers lack money to buy seeds, which affects her ability to procure vegetables.
  7. Jerry (Interview 11)
    - o Describes having to visit markets multiple times to check seed availability. Seed shortages delay production.
  8. Jack (Interview 13)
    - o Reports 2–3 month waits for onion, broccoli, and cabbage seeds; low germination from small store seeds.
  9. Karl (Interview 14)
    - o Seed stock runs out quickly, forcing him to wait; cost has increased. Packet seeds have poor germination.
  10. Frank (Interview 15)
    - o Faces 1–2 month wait periods and hoarding of seed stock by others; has to visit shops 15 times a month sometimes.
  11. Jason (Interview 16)
    - o Halts farming when seeds are out of stock. Waits 1–2 months for restocks. No supplier contact info.
  12. Jo (Interview 12)
    - o Seed stock runs out quickly, alternative stores charge more, no extension officer support.
  13. Bob (Trader, Interview 5)
    - o Mentions he provides avocado seeds to farmers to support their planting. Implied need due to lack of seed access.
  14. Alex (Trader, Interview 6)
    - o States his farmers "do not have enough money to buy seeds".

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Interviews Without Seed-Related Issues

### 15. Mason (Interview 8)

- o Does not buy seeds; relies fully on saved tomato seeds from harvest.

### 16. Ellen (Trader, Interview 10)

- o No mention of facing seed constraints herself; however, she provides seeds to farmers—suggests indirect evidence of scarcity, but she doesn't report it as her own constraint.

## 2. Aggregators.pdf

Number of interviews with seed-related issues: 6 out of 6 interviews

Evidences:

- Interview 17 (Caitlin): Notes that shortfalls in supply are often due to inadequate access to seeds among farmers.
- Interview 18 (Sam): Reports that he had to wait over a month for tomato and carrot seeds.
- Interview 19 (SUN, Allen): Farmers face frequent stock shortages at Brian Bell; some switch crops due to seed unavailability.
- Interview 20 (Talent): Their input division struggles to import enough seeds; demand exceeds supply.
- Interview 21 (Joe): Mentions that his farmers wait several months for certain seeds, disrupting supply.
- Interview 22 (Patriot Suppliers): Notes that unavailability of seeds and chemicals delays planting cycles and affects consistency of supply.

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## 3. Input suppliers.pdf

Number of interviews with seed-related issues: 3 out of 3 interviews

Evidences:

- Interview 23 (Mr. Fang, general store): Started importing seeds due to high unmet demand from farmers when main suppliers ran out.
- Interview 24 (Brian Bell): Reports frequent stockouts, especially for cabbage and broccoli. Large packages (cheaper per unit) are often unavailable.
- Interview 25 (Farmset): Reports 2 to 6 months stock shortages, especially for onion and tomato seeds. Demand is high, but imports are limited by the depreciating Kina.

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## 4. Transporter.pdf

Number of interviews with seed-related issues: 0 out of 1 interview

Evidence:

- Interview 26 (Ben): Focus is entirely on transportation logistics; no mention of seed issues.

### ***B3. ChatGPT-o3's Deep research on Seed-related issues:***

Prompt: "Based on all the files, how many interviews reported any issues/constraints/challenges regarding seed, both explicitly and implicitly? Please provide references/evidence."

The following is a response generated by ChatGPT in GPT-o3 mode with "Deep research" option:

#### Lead Farmers (Interviews 1–16)

14 out of 16 lead farmer interviews mention seed-related constraints. Common issues include seed shortages, high seed costs, and difficulties obtaining seeds (e.g. long delays or distant travel to purchase them). For example:

- Interview 1 (Terry, lead farmer): Cited "seed shortage" alongside weather shocks and transport as major issues disrupting vegetable production. He noted needing support so farmers can afford more inputs like seeds to improve production.
- Interview 2 (Bob & Sam, lead farmers): Described chronic seed supply delays – they often faced "delays of 3 to 4 months" in acquiring needed seeds and sometimes had to travel 2 hours to Goroka or even a full day to Lae to find seeds.
- Interview 3 (Dyson, lead farmer): Reported local input shops frequently being out-of-stock of the seeds he needs, forcing him to drive 2 hours to Goroka – where he still "couldn't source the seed products" because many vegetable seeds were unavailable and larger packages were often sold out. He added that the seeds in shops are "a bit expensive" for him, limiting him from buying his ideal seed varieties.
- Interview 4 (Ethan, lead farmer): Relies partly on saved seed because the nearest shop in Kainantu is out-of-stock on more than half of his visits. He must then go to Goroka or Lae to buy seeds, incurring extra bus fares (20–40 Kina), which indicates both availability and cost challenges.
- Interview 6 (Alex, vegetable trader): Works with farmers who "do not have enough money to buy seeds," meaning limited seed access due to affordability issues. This lack of capital for inputs among his farmers constrains their production.
- Interview 7 (George, lead farmer): Typically buys seeds from a major supplier but noted if seeds are "unavailable" there he must go to other stores. Seeds from small retail shops are usually more expensive than those from his primary supplier, highlighting availability problems and higher costs at alternative sources.
- Interview 9 (Grace, lead farmer & trader): Explained that her farmers lack the finances to purchase seeds, which diminishes their production quantity and quality. This shortfall in output often poses a challenge for Grace in fulfilling orders.

- Interview 10 (Ellen, trader): Observed that a “shortage of seeds among farmers” makes it hard for her to get enough produce, so she began supplying seeds to those farmers herself. She purchases seeds from a main supplier (Brian Bell) and if they’re out of stock there, she resorts to local roadside stores.
- Interview 11 (Jerry, lead farmer): Noted that it’s common to make multiple trips to town checking for seed availability. If seeds are out of stock, he has to wait for restocking, which delays his planting. He avoids buying from smaller shops or “Asian” stores because their seed prices are beyond his budget.
- Interview 12 (Jo, lead farmer): Also finds he “not always get the seeds he wants” because stock at major stores runs out quickly. In those cases he visits mini retail, hardware, or Asian shops, but their seeds are at a higher price. Moreover, he receives no institutional support for procuring seeds. He buys seeds quarterly, which takes him an entire day traveling to town and back.
- Interview 13 (Jack, lead farmer): Detailed that the farmers in his cooperative often encounter seeds being out-of-stock at the main suppliers. They sometimes have to wait 2–3 months for certain seeds (onion, broccoli, cabbage) to become available. Some tried buying cheaper seeds from small Asian shops, but those had a low germination rate, so they stopped using them despite the lower price. This illustrates both availability and quality issues with seeds.
- Interview 14 (Karl, lead farmer): Focuses on onions and noted the local input store’s seed stock “finishes quickly” due to high demand, so he often waits for it to be replenished. He prefers large tins of seed (small packets “don’t always sprout”), but the larger packs sell out fast. He also faces “high costs of seeds”, which pose a financial challenge for his farming operation.
- Interview 15 (Frank, lead farmer): Manages a large farmer network and tries to secure seeds for them. He’s observed that seeds from Asian stores germinate only ~60%, so he seeks help from FPDA to improve seed access. Even so, if seeds at the major suppliers are unavailable, his group may wait “1–2 months” for new stock. When seed packets do arrive, they are quickly hoarded by farmers and buyers, causing the stock to deplete almost immediately.
- Interview 16 (Jason, lead farmer): Confirmed that seed stock-outs are a common issue. When seeds aren’t available in shops, he often has to wait 1–2 months for restocks. In the meantime he halts planting or switches crops to those for which he has seed on hand. He even makes weekly trips to town to check for seeds, as he has no supplier contacts to call – spending time and money (bus fares) due to the uncertain seed supply.

#### Aggregators (Interviews 17–22)

All 6 aggregator interviews brought up seed-related challenges, since aggregators depend on farmers having adequate inputs. Common themes include farmers’ lack of access to seeds leading to supply shortfalls, and seeds being too costly or unavailable in time. For example:

- Interview 17 (Caitlin, aggregator): She noted that about one-third of her supply shortfalls are due to farmers’ difficulties, including “inadequate access to seeds for cultivation”. In trying to scale up, she finds that shortages of seeds (as well as chemicals and tools) among her farmers “hinder their capacity to expand” production.
- Interview 18 (Sam, aggregator): Described input procurement issues: he mainly buys seeds from a large store, but sometimes could not get tomato or carrot seeds and “had to wait for more than 1

month” for restocks. Additionally, “the costs of seed, chemicals, and fertilizers are too high” for him, which squeezes his margins and limits expansion.

- Interview 19 (Allen, SUN aggregator): Highlighted persistent seed supply problems in his area. For instance, farmers trying to source onion seed from the main supplier face frequent stock shortages, forcing them to endure trips to Goroka 2–3 times a month (half a day each) in search of reliable seeds. Despite these efforts, inconsistent seed availability remains a primary challenge for SUN’s network, making seed access one of their “main constraints”.
- Interview 20 (Talent/Hello Fresh aggregator): This business even operates a seed-importing division, yet “their seed supply tends to deplete quickly, impacting local farmers’ production.” It has proven difficult to import seeds fast enough to meet demand, similar to the shortages seen with other inputs like fertilizer. In short, even the aggregator’s own stores struggle to keep seeds in stock for farmers.
- Interview 21 (Joe, aggregator): Pointed out that the biggest constraint to maintaining a steady vegetable supply is “the unavailability of seeds” for his farmers. Growers often have to wait several months for certain seeds, which disrupts the consistency of vegetable production. Such seed delays directly translate to inconsistent volumes for his aggregation business.
- Interview 22 (Patriot Suppliers, aggregator): Similarly experiences delays in farmers’ planting cycle and on-time supply “due to the unavailability of seeds... from the input suppliers.” When this happens, they resort to buying seeds (and produce) on the open market at higher cost or asking other farmers to fill the gap. The Patriot team noted that seed unavailability can cause a cascading “ripple effect” across the whole chain – from farmers to aggregators to buyers – leading to an inconsistent supply of vegetables.

#### Input Suppliers (Interviews 23–25)

All 3 input supplier interviews directly discuss seed supply issues (since these are the sellers of seeds). They confirm frequent stockouts and high demand for seeds, as well as some causes of these shortages. For example:

- Interview 23 (General store seed seller, Goroka): The owner (Mr. Fang) started selling vegetable seeds after observing that local farmers “struggled to procure essential vegetable seeds.” His first imported seed stock sold out rapidly due to high demand. He notes that several small Asian-run shops like his now “bridge the gap in the supply of vegetable seeds” during times when big suppliers (e.g. Brian Bell, Farmset) struggle with consistent stock. Farmers have even said that relying only on the large outlets sometimes left them unable to get specific seeds they need, so they turn to these smaller stores which often offer more affordable seed options.
- Interview 24 (Brian Bell input shop, Goroka): The store manager admits certain seed types frequently go out of stock. For example, cabbage seed was “unavailable for over a month” and broccoli seed for over 5 months at one point. The larger seed packages (which are cheaper per unit) are especially popular and often unavailable. He attributes these shortages partly to the weak Kina (currency), which limits their ability to import seeds due to higher costs.
- Interview 25 (Farmset input shop, Goroka): According to this manager, seeds for crops like onion and tomato “frequently face stock shortages.” The big, cost-effective seed tins are often sold out for “about 2 to 6 months” at a time. The causes noted are similar – depreciation of the Kina making imports harder, and surges in overseas demand (e.g. during COVID-19) creating local seed shortages. In short,

even though seeds are a small part of their business, demand is very high and supply can't always keep up.

Transporter (Interview 26)

The transportation interview did not mention any seed-related constraints. The transporter focused on logistics issues (road conditions, vehicles, etc.) rather than input supply. 0 out of 1 interviews in this category noted seed problems, indicating that seed access was not a direct concern in the transporter's operations (his role is moving produce, so seed issues were outside his scope).

#### ***B4. ChatGPT-4o's Normal Search on Transportation-related issues:***

Prompt: "Based on all the files, how many interviews reported any issues/constraints/challenges regarding transportation or infrastructure, both explicitly and implicitly? Please provide references/evidence."

The following is a response generated by ChatGPT in GPT-4o mode, which identified a relatively limited number of interviews referencing transportation-related constraints:

Our prompt: "Based on all the files, how many interviews reported any issues/constraints/challenges with transportation or infrastructure, both explicitly and implicitly? Please report by interviewee type."

The following is the response by ChatGPT under *Normal Search* mode:

##### 1. Lead Farmers.pdf

File contains interviews with lead farmers and traders (Terry, Bob & Sam, Dyson, Ethan, George, Mason, etc.)

A total of 8 out of 9 interviews mention transportation or infrastructure issues.

Examples:

Terry (Interview 1):

"When it rains, the roads become damaged, causing delays in transporting the produce, during which the crops may spoil."

"Vehicles often break down due to poor roads."

Bob & Sam (Interview 2):

"Due to poor feeder road conditions on rainy days, it is hard to arrange PMV service..."

Dyson (Interview 3):

"Poor condition of feeder road during the rainy days"

Ethan (Interview 4):

"The main issue in transporting vegetables is poor road conditions of the feeder road on rainy days."

George (Interview 7):

"Arranging transportation is a significant challenge for him... potatoes can become damaged during delays."

Mason (Interview 8):

"Prolonged waits for PMVs... other people's bags damaging his tomato buckets."

Bob the trader (Interview 5):

"Poor road conditions, road accidents, and traffic congestion... quality of packaging is inadequate to protect crops during rain."

Alex the trader (Interview 6):

"Waits for random trucks... intoxicated drivers, bad roads during wet season delay delivery."

## 2. Aggregators.pdf

File includes interviews with aggregators (Caitlin, Sam, SUN, Talent/Hello Fresh)

All 4 aggregators raised transport or infrastructure concerns.

Examples:

Caitlin (Interview 17):

"Shortfalls are attributed to farmers' difficulty delivering produce due to poor feeder roads."

"Vegetables are susceptible to bruising in dry containers; irregular shipping schedules increase spoilage risk."

Sam (Interview 18):

"Shipping by sea is costly and risky; four aggregators went out of business due to large losses during sea shipping."


SUN (Interview 19):

"Challenges in transportation of produce... they invested in trucks and cold storage to mitigate this."

Talent (Hello Fresh, Interview 20):

"Roadblocks and floods hinder transport from Mt. Hagen to Lae; vegetables often get damaged en route."

### 3. Transporter.pdf

 Interview with Ben, vegetable transporter

The sole interview clearly discusses road and logistics constraints:

Examples:

Ben (Interview 26):

"Feeder road's precarious condition becomes especially treacherous during periods of rain."

"Vegetable transport to Lae wharf takes two days including 2-hour loading at farm gates."

### ***B5. ChatGPT-o3's Normal Search on Transportation-related issues:***

Prompt: "Based on all the files, how many interviews reported any issues/constraints/challenges regarding transportation or infrastructure, both explicitly and implicitly? Please provide references/evidence."

Aggregators.pdf

6 of 6 interviews (17 – 22)

# Interviewee Evidence of constraint

17 Caitlin Farmers "face ... difficulties in delivering produce due to poor feeder roads"; sea-freight bruising & irregular sailings hurt quality.

18 Sam Pays K 50-100/bag for cooled sea-freight; four peers “went out of business” after heavy sea-shipping losses.

19 SUN (Allen) Co-op founded to “alleviate ... transportation costs” that weigh on farmers.

20 Hello Fresh “Roadblocks and floods hinder transportation from Mt Hagen to Lae”; container damage in shipping.

21 JoeRegular Highland-highway blockages force mid-route trans-loading to another truck.

22 Patriot 12-hour hauls on bad roads, frequent disruptions, no chiller trucks, rising fuel costs.

Total: 6 interviews

Lead Farmers.pdf

16 of 16 interviews (1 – 16)

Every lead-farmer or trader raised transport or road-infrastructure problems—washed-out feeder roads, lack of PMVs, long truck waits, shipping expense, produce damage, or the need to hand-carry produce. Examples:

#1 Terry – rain-damaged roads delay deliveries and spoil crops.

#5 Bob (trader) – “Transportation is a major issue due to poor road conditions, road accidents, traffic congestion and landslides.”

#8 Mason – crowded PMVs crush tomato buckets; long waits cost him a market stall.

#12 Jo – harvest ready but “trucks are not always available”; no storage if pickup is late.

#13 Jack – “Hard to arrange PMV service, and the cost is high.”

Total: 16 interviews

Transporter.pdf

1 of 1 interview (26)

Ben (transporter) cites a “precarious” feeder road, especially in rain, as his main obstacle.

Total: 1 interview

## ***B6. ChatGPT-o3's Deep research on Transportation-related issues:***

Prompt: "Based on all the files, how many interviews reported any issues/constraints/challenges regarding transportation or infrastructure, both explicitly and implicitly? Please provide references/evidence."

Lead Farmers.docx

All 16 interviews with lead farmers mention transportation or infrastructure challenges. These range from bad road conditions and vehicle breakdowns to reliance on public transport. For example:

- Interview 1 (Terry, Lead Farmer): He cites "reliable transportation" as a major issue when procuring vegetables. He notes that heavy rains damage roads and cause delays in transporting produce.
- Interview 2 (Bob & Sam, Lead Farmers): Poor feeder road conditions in rainy weather make it "hard to arrange PMV service," preventing some farmers from delivering vegetables. Bob and Sam must find alternate suppliers when partners can't reach them due to road issues.
- Interview 3 (Dyson, Lead Farmer): Lists "Poor condition of feeder road during the rainy days" as a key challenge. He also saved on a 300 Kina transport cost per trip by no longer hauling produce 6 hours to Lae himself, underscoring the high cost and burden of transportation.
- Interview 4 (Ethan, Lead Farmer): "The main issue in transporting vegetables is that poor road conditions of the feeder road on rainy days." Even living only 5 miles from the buyer, bad roads in wet seasons hinder his deliveries.
- Interview 5 (Bob, Vegetable Trader): Transportation is a major issue for him due to "poor road conditions, road accidents, traffic congestion, and landslides," which hinder timely delivery. He often waits hours (sometimes all day) for trucks, and if it rains while waiting on the road, his bags of produce can spoil.
- Interview 6 (Alex, Vegetable Trader): Describes waiting 3-4 hours for trucks and says the long haul to Lae is his biggest challenge. Bad road conditions in the wet season delay the journey significantly. He aspires to own a truck to ensure more reliable transport.
- Interview 7 (George, Lead Farmer): "Lastly, he grapples with logistical challenges, particularly during the transportation of his produce from the farmgate to Goroka." This transportation difficulty is singled out as a major concern in his interview.
- Interview 8 (Mason, Lead Farmer): Relies on PMVs (public buses) and must carry produce on foot to the main road. On busy days, he waits a long time for a PMV, which can cause him to lose his market spot. He notes items can get damaged when piled in the bus, and delays often occur due to full vehicles.
- Interview 9 (Grace, Lead Farmer/Trader): Even though she has buyers pick up from her house, she "still encounters transportation issues" — sometimes PMVs or trucks arrive late to collect vegetables. Lack of her own vehicle also limits her reach: without transport she "is unable to explore other rural markets" to buy cheaper produce.

- Interview 10 (Ellen, Trader): Road infrastructure is her biggest complaint. She explicitly cites landslides, floods, and broken bridges – “poor conditions” that mean produce doesn’t reach the market on time and can cause major delays.
- Interview 11 (Jerry, Lead Farmer): When selling at the open market (no buyer pickup), he and his wife must carry bags of vegetables for about 1 hour from farmgate to the market. The market itself also “does not have good infrastructure or a proper roof,” an additional infrastructure issue he mentions.
- Interview 12 (Jo, Lead Farmer): Describes long waits for aggregator trucks. “The waiting time is long, as trucks are not always available,” which is a noted transportation challenge. If the aggregator delays pickup, farmers have no storage and risk spoilage. Jo also carries unsold stock to market by bus, paying fares and hauling bags to the road himself.
- Interview 13 (Jack, Lead Farmer): “Transportation is a big challenge for Jack.” In the rainy season, he must spend 45 minutes carrying vegetables from his farm to the main road for pickup. He notes arranging a PMV can take hours, and transport is his largest cost, even forcing him to borrow money to cover it.
- Interview 14 (Karl, Lead Farmer): Stopped selling in distant cities because he “needed more money to cover the transportation costs”. Locally, he uses a wheelbarrow to move produce to the road. He says “transportation from farmgate to roadside is very labor intensive and requires strength”, highlighting the physical strain due to lack of direct road access or vehicles.
- Interview 15 (Frank, Lead Farmer): Lacks a vehicle and struggles to hire transport. “No car or PMV availability” increases his costs in time and money to find alternatives to get his produce from farm to market. He often must go to town to hire a PMV for 100 Kina per trip since none operate in his village.
- Interview 16 (Jason, Lead Farmer): Faces multiple transport issues. He waits a long time for PMVs to go to Lae, and has no wheelbarrow, so he makes many manual trips carrying produce to the main road. This is physically demanding, and he sometimes pays youths to help. He calls these delays and lack of equipment his “biggest challenge” in getting produce to market.

#### Aggregators.docx

All 6 interviews with aggregators mention transport or infrastructure constraints, often revolving around bad roads and high transport costs:

- Interview 17 (Caitlin, Aggregator): About one-third of her supply shortfalls are “attributed to...difficulties in delivering produce due to poor feeder roads” in farmers’ areas. She also notes inadequate feeder roads make it hard for farmers to transport vegetables to her facility.
- Interview 18 (Sam, Aggregator): Initially shipped vegetables to Port Moresby, but encountered high transportation costs – “50 to 100 Kina per bag” – because he had to use cooled shipping containers. Working with a closer buyer (Lae) improved profits “thanks to the large cost-saving from not going to POM.” Delayed payments aside, transport was a key expense that constrained his early business.
- Interview 19 (Allen, SUN Cooperative Manager): The cooperative was founded to alleviate farmers’ transportation costs. SUN invested in trucks and even motorbikes for farm pickup, because previously farmers had to bear heavy transport burdens. (Allen doesn’t report road problems himself, but the very mission of SUN highlights transport cost as a constraint for farmers.)

- Interview 20 (Talent/Hello Fresh Aggregator): Operates a fleet of cooler trucks from Mt. Hagen to Lae and then ships to POM. They describe specific “Transportation Challenges”: roadblocks and floods hinder the route from Hagen to Lae, and sometimes vegetables are damaged in transit. If shipment problems occur (e.g. delayed or spoiled en route), their buyers suspend orders and source elsewhere, directly tying infrastructure issues to business risk. During COVID, fewer farmers came to town, so the company had to pay extra to collect from farms, raising their operating costs.
- Interview 21 (Joe, Mt. Hagen Aggregator): He sometimes dispatches PMV trucks to town to gather produce. Road disruptions on the Highland Highway frequently interfere with his vegetable deliveries – “PMV sometimes ran into road disruptions” – and he had to send an alternate truck to avoid delays. These highway blockages pose a risk of losses if not navigated.
- Interview 22 (Patriot Suppliers, Aggregator): Runs long-haul deliveries (~12 hours) to supply a buyer. He “most often ran into road disruptions”, which hurt the quality of his produce. The road conditions are very bad, and fuel and transport costs are extremely high due to the long distance. These infrastructure problems cut into his supply reliability and profits.

Input suppliers.docx

0 interviews mention transport or infrastructure constraints in the input suppliers notes. The three interviews (an Asian general store and two chain input stores) focus on seed availability and pricing issues, not on transportation problems. For instance, they discuss seed stock shortages and farmers seeking alternative suppliers, but no challenges related to roads or transport are raised in these interviews.

Transporter.docx

The transportation provider interview highlights critical infrastructure issues.

- Interview 26 (Ben, Vegetable Transporter): Ben has 40 years in hauling produce. He specifically “faces a significant challenge” with the feeder road’s poor condition, which becomes “especially treacherous” in the rain. Early in his career, he saw how hard it was to transport crops long distances and started a PMV service to fill that gap. He has had to replace or upgrade his trucks multiple times to handle the rough conditions. His newest large PMV improved capacity, but the bad feeder roads still pose a major problem during wet weather, affecting reliability and safety.



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