ASSESSING THE IMPACTS OF POTENTIAL INTERVENTIONS ON VEGETABLE CONSUMPTION IN URBAN KENYA USING PARTICIPATORY SYSTEMS MODELING

GAIN Working Paper n°22

October, 2021

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Recommended citation

Nicholson C, Monterrosa EC. Assessing the Impacts of Potential Interventions on Vegetable Consumption in Urban Kenya Using Participatory Systems Modelling. Global Alliance for Improved Nutrition (GAIN). Working Paper #22. Geneva, Switzerland, 2021. DOI: https://doi.org/10.36072/wp.22

Acknowledgements

The authors wish to acknowledge thoughtful reviews from Eric Djimeu Wouabe, Stella Nordhagen, and Saul Morris.

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SUMMARY

Efforts to increase the consumption of vegetables focus on addressing availability, accessibility, and desirability, usually through a value chain approach. We sought to build on this value chain approach by using participatory systems modelling to address the relatively stable daily per capita vegetable consumption in Nairobi, Kenya over the last 15 years.

The participatory systems modelling combined system dynamics modelling with a participatory process via two workshops. In the first workshop, stakeholders' views were solicited to construct a conceptual model of linkages (a causal loop diagram). In the second workshop, stakeholders assessed potential responses of value chain actors to various interventions. The information from the workshops was used to build and refine a simulation model, complemented by data from the literature. This simulation model was then used to assess six different classes of interventions: consumer awareness, vegetable quality, convenience, farm costs, farm perishability, and farm yields. The outcome, vegetable consumption, was highest (at 171 (122, 206) g/day [median (minimum, maximum)]) with increasing farm yields; however, combining the six interventions delivered the largest change, 198 (170, 209) g/day, suggesting synergies with multiple value chain interventions. Additional analysis of implementation costs would complement assessment of simulated consumption changes.

The participatory systems modelling process has the potential to strengthen programme planning efforts by identifying different classes of interventions across the value chain that can improve vegetable consumption. Drawing on the model's findings, GAIN identified which of its programmes in Kenya could be deployed for this objective. Further knowledge development is needed to refine the model.

KEY MESSAGES

- Current programmatic practice usually involves descriptive and linear approaches, like value chain analysis, and does not provide a mechanism for analysing the complex causal interactions among value chain actors or how interventions can change a nutrition outcome over time.
- Participatory systems modelling builds on value chain analysis but addresses these limitations, providing a mechanism for incorporating both quantitative data and stakeholder input via a causal loop diagram and a simulation model. The simulation model is then used to assess interventions to change a nutrition outcome over time.
- Applying this approach to the case of vegetables in urban Kenya yielded critical information for programme planning that would not be obtained through more traditional value chain analysis: it provided estimates of the potential impacts on the nutrition outcome of interest and a time period for when those changes might be achieved.
- The participatory process is useful for identifying the complexity of the value chain and data gaps regarding actors' responses to various interventions. Participatory systems modelling has the potential to strengthen programme planning efforts in development organisations.

BACKGROUND AND OBJECTIVE

Poor diets are considered a major contributor to the non-communicable disease burden (1) as well as undernutrition (2). Increasing fruit and vegetable consumption is one way to achieve higher quality of diets. These foods are generally good sources of fibre and micronutrients, consumption of which can reduce risk of hypertension and cardiovascular disease (2,3). Greater consumption of plant-based foods, such as fruits and vegetables, in place of animal-source foods can also help make dietary patterns more environmentally sustainable (4).

The WHO recommends a minimum consumption of 400 g/day/person of fruits and vegetables, which has often been translated into "five servings per day" (5). Miller et al. (6) report that the global average consumption is 3.76 servings[1] (95% CI 3.66–3.86) per day, but consumption worldwide varies significantly. Whereas in high-income countries average consumption (5.42 servings, 95% CI 5.13–5.71) exceeds the minimum recommended servings, average consumption in low-income countries (2·14 servings, 95% CI1·93–2·36) and lower-middle-income countries (3.17 servings, 95% CI 2.99–3.35) fails to meet the recommendations. Fruits and vegetables in low- and middle-income countries (LMIC) are expensive compared to starchy staples (7), and mean fruit and vegetable intake decreases across quartiles of relative cost of five servings of fruits and vegetables within LMICs(6).

The relative affordability of fruits and vegetables may also be driven by low availability. Many African countries do not produce enough vegetables to meet their populations' nutrient needs (8,9). This low production is exacerbated by high food losses in the value chain. Vegetable yields in Kenya, for example, are variable, ranging from 8 to 18 tonnes/ha, depending on the crop (10). Post-harvest loss in fruit and vegetable value chains is estimated at between 20-38% in Kenya (11). Vegetable consumption is seasonal, and prices fall during harvest season. Fruits and vegetables in Kenya account for about 25% of the household food budget (12); green leafy vegetables (GLV) are the least inexpensive vegetables (13).

In Kenya, an LMIC, the per capita consumption of fruit and vegetables has been relatively stable over the last 15 years, at about 260 g/day (approximately 3.25 servings[2]), despite a doubling of the GDP per capita over the same period, from 1,516 to 3,361 USD per person (14). About 95% of Kenyans do not consume the recommended five daily servings of fruit and vegetables (15). In Kenya, vegetable consumption is lowest among urban dwellers, men, young adults (15-45 years), those with higher education, and large households (16). While Kenyans are generally aware of the health benefits of vegetables, desirability of vegetables is low, with some GLV regarded as food for the poor (17,18).

In the field of nutrition, efforts to increase the consumption of fruits and vegetables often centre on changing consumer preferences and choice (19). This focuses naturally on the *desirability* of consuming fruits and vegetables, but the use of fruits and vegetables in the local cuisine, as well as the functioning of the supply chain, can also affect their *availability*, *affordability,* or both. In Kenya, like in many places, vegetables are usually a culinary

[1] In the Miller et al. study, 1 serving = 125 g.
[2] If the 400 g/day recommendation is equal to five servings, then in this paper assume that one serving is 80 grams.

ingredient, meaning they are used in dishes and meals, while fruits are consumed between meals, as a beverage, after meals (as dessert), or during special festivities. Thus, cultural habits more broadly, and meals specifically, are drivers of purchases and consumption. In this project we focus on vegetables, since their use is distinct to that of fruits. With regards to availability, a GAIN supply chain analysis of vegetables in Kenya revealed that 95% of vegetables in Nairobi are sourced from within a 150-km radius (20). Because it is easy to enter the vegetable trade, the supply chain consists of multiple players and informal actors (e.g., brokers and hawkers).

Using a value chain (VC) framework is useful for the assessment of potential interventions to improve vegetable consumption, and analyses using a VC framework to assess nutritional outcomes have become more common in the past decade (21). Figure 1 shows the typical structure of a value chain. However, analytical methods based on these frameworks must account for the multiple interactions among actors, because supply chains can demonstrate dynamic complexity, i.e., unexpected outcomes and differences in short- and long-term responses. System dynamics (SD) modelling is a method that can explicitly represent the complex interactions among VC actors and capture dynamic complexity. This approach emphasises the description of a VC as linked stock, flow, and feedback processes, adopting a "systems lens" to describe how the value chain evolves over time, rather than describing its current status or a series of discrete, linear responses to events. An SD approach can also involve stakeholders in a participatory process of model development and use, often referred to as Group Model Building (GMB), which enhances engagement and use of the information generated (22). Given the potential benefits of a VC analysis facilitated by a participatory approach, GAIN invested in a pilot project to evaluate the usefulness of participatory systems modelling for the assessment of interventions to increase vegetable consumption in the Nairobi area. Previous work based on SD modelling has explored factors affecting overweight and obesity (23), but to our knowledge this is first use of SD modelling to assess alternatives to increase consumption of healthy foods.

Figure 1. Diagram of a value chain. Source Supply Chain Analysis for Nutrition Tool (24).

OBJECTIVE

The main purpose of this project was to assess the usefulness of participatory SD modelling in support of GAIN's programme-planning efforts. As noted above, SD modelling was selected to facilitate the assessment of complex value-chain linkages, with a focus on outcomes over time (25). In framing the problem as a system, we sought to achieve three specific objectives:

1. **Characterise the demand and supply side linkages** in the vegetable value chain based on causal pathways rather than descriptive information;
2. **Develop a quantitative systems model** to represent the vegetable chain and evaluate proposed interventions to increase consumption;
3. **Assess the extent to which participatory systems modelling** could provide relevant and actionable information in this context.

From a planning process perspective, it was also important for GAIN senior staff to examine if the participatory systems modelling process could include and make use of existing organisational resources (e.g., GAIN supply chain assessments) and published literature, and if the simulation model was useful for strategic decision-making, (e.g., did it provide a clear set of interventions and hypothesised pathways to impact?).

METHODOLOGY

Improving access to nutritious and safe foods usually involves a value chain approach (VCA) (26). VCA is a generic term that broadly captures the ways in which economic and nutritional value is added or nutritional losses minimised throughout the value chain. This approach emphasises the need for coordinated action to improve dietary outcomes.

In applying a VCA, one seeks first to identify the value chain stages, then identifies high-leverage points along the value chain by drawing on data from value chain assessments and existing published evidence to address gaps in availability, affordability, and/or desirability of nutritious foods (27). A VCA typically culminates in a description of the value chain and identification of actions around leverage points, rather than seeking to capture the complexity of the system (21), though some VCAs may identify two-way causal linkages between variables.

SD models can build on many of the principles of a VCA, such as examining the various stages of the value chain and the economic value of its activities. SD models also rely on similar information sources, such as value chain assessments, stakeholder perspectives via participatory model building, and reviews of published literature. Unlike VCA, SD modelling has the capacity for consolidating information from diverse data sources into a quantitative model. It also differs in its application of a systems view, with a focus on system behaviour (a nutrition outcome of interest, such as consumption of vegetables) over time and the identification of higher-leverage interventions that impact the system behaviour.

This project employed a participatory systems modelling approach, which included SD modelling as described by Sterman (28), GMB as described by Vennix (22), and an extensive document review, which drew from GAIN's analyses of the GLV and tomato value chains in Kenya (20), using GAIN's Supply Chain Analysis for Nutrition (SCAN) Tool (24), as well published value chain literature with a focus on vegetables in Africa and globally. The project was structured to allow iterations between expert knowledge, published literature, and feedback from GAIN staff. The key steps in this process included:

1) development of a conceptual model of the linkages in the vegetable supply chain and potential intervention points using a participatory process with stakeholders;

2) transforming the conceptual model into a quantitative dynamic simulation model based on input from stakeholders, previous supply chain models, and empirical evidence from the literature;
3) assessing the quantitative model with standard evaluation approaches and stakeholder input;
4) using the model to assess the impacts of potential interventions to increase vegetable consumption; and
5) identification of priority actions for implementation and additional information needs.

The project was led by an outside expert in SD modelling and GMB, with GAIN providing strategic and operational support.

Group Model Building. We held two workshops in Nairobi. The first comprised two half-day sessions on 12-13 September 2019 and included 16 participants with different perspectives on the Kenyan vegetable value chain. The second participatory workshop was held on 16 April 2020 (via Zoom video-conferencing software due to Covid-19 travel restrictions). The April workshop included many of the stakeholder participants from the September workshop.

The purposes of the September workshop were to solicit input from relevant stakeholders about the factors that have limited increases in vegetable consumption in Nairobi and to increase awareness of the complexity of value chain interactions that could limit the ability to affect change. Consistent with the approach described in Vennix (22), participants (n=18) were led with a series of scripts to identify factors affecting a "reference mode" behaviour over a relevant time horizon. The "reference mode" behaviour depicts a key metric (outcome) for which the underlying causes are to be determined and for which improvement is desired. In this workshop, the low and stagnant level of vegetable consumption was defined as the "reference mode." During the introduction, participants were provided with information about the overall process for the project, the structure of the workshop, an operational definition for vegetables, and an illustrative listing of value chain stakeholders. The first workshop was divided into three parts:

- Identify the factors affecting vegetable consumption
- Describe and define affordability, desirability, and availability relevant to vegetable consumption
- Identify priority interventions to increase vegetable consumption

The primary purpose of obtaining this information from the September workshop was to develop an initial conceptual model (a systems map) capturing the concepts and linkages relevant for the development of the quantitative simulation model. Following the September workshop, participants were asked to provide a ranking of potential interventions, so that the impacts of interventions considered high priorities could be included in the model structure. A subset of these interventions at the farm, intermediary, and consumer levels (Table 2) was selected by GAIN staff for representation in the quantitative model.

The April workshop solicited additional input from participants (n=8) on the responsiveness of value chain actors (e.g., consumers) to various types of changes (e.g., increased demand due to better quality), and on how quickly (slow, moderate, or rapid) these changes would be made by the actors. Participants also completed a priority ranking (first, second, and third priority) for a set of consumer-facing interventions and a set of interventions focused on other actors in the value chain. The workshop included an initial discussion of the key elements of the interventions, with additional one-to-one discussions after the workshop with the individuals deemed most knowledgeable about the intervention. These discussions focused on several elements, including:

> The <u>specific measurable indicator</u> to evaluate changes caused by the proposed intervention (e.g., what aspects of produce 'quality' would be modified by an intervention to 'improve quality'?)
>
> The <u>degree of change</u> likely to be possible in the indicator based on the current situation (e.g., by how much (e.g., percentage change) could 'awareness of nutritional benefits of vegetables' be increased based on current levels of awareness?)
>
> The <u>actions required by value chain actors</u> or external partners to implement the intervention (e.g., what actions by farmers or input suppliers are required to increase yields?)
>
> The <u>impact on costs</u> throughout the value chain of the proposed intervention (e.g., what would the impact be on unit costs of increased safety and hygiene for vegetables?)
>
> The <u>time required to implement the changes</u> implied by the intervention (e.g., how long would be required for development of farmer training programmes to lower production costs?)

Each of these elements is important to determine the impacts of an intervention in a systems-modelling context. They also provide some initial logical assessment of the potential impact of interventions when limited change in the indicator is likely to be possible. For example, if awareness of the nutritional benefits of vegetables among consumers is already high, this suggests that interventions to increase consumer awareness are likely to have small impacts on consumption. Low initial awareness can provide additional scope for improvement, but the potential benefits of the intervention would also depend on the responsiveness of consumers to awareness and the impacts of increases in awareness on other value chain actors and their decisions.

Quantitative systems model. Drawing on the information from the September workshop, a quantitative systems model was developed using the SD modelling approach. Elements of the model derive from the supply chain model in Sterman (28), modified for the purposes of this project. Farm production, intermediaries[3], and vendors reflect multiple linked value chain actors in supply chains for vegetable products. The development of the model requires empirical evidence about the nature and magnitude of causal linkages. Relevant literature on vegetable value chains in Kenya and related to consumer behaviour was used to develop specific quantitative relationships among the variables identified in the stakeholder workshop.

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[3] *Intermediaries* are defined for the purposes of the model as the first buyer of a product from farmers and the sellers of product to *vendors*, who are assumed to sell directly to individual consumers (households). This is a simplification in the sense that there can be multiple intermediaries between farmers and vendors, but this aggregation likely does not affect the outcomes of the model.

In Sterman's (28) commodity supply chain model formulation, prices from sellers to buyers are determined by inventory coverage (the amount of product in storage at a market level divided by current sales and expected product losses—spoilage). Sales prices generate revenues, which, along with costs for production and distribution, determine profits. Profitability of farmers, intermediaries, and vendors determines the level of initiation of new production (for farms) or marketing (purchases/orders, for intermediaries and vendors), which become part of available inventories with a delay (e.g., time is required to increase production and to contract for purchases and receive deliveries from suppliers). Prices also determine the demand for the product from intermediaries, vendors, and consumers.

Although in some value chain models, perfect coordination is assumed (orders are coordinated throughout all levels of the supply chain), we do not assume that the vegetable supply chain for Nairobi demonstrates this degree of coordination. Rather, farmers, intermediaries, and vendors are assumed to operate independently and thus may make supply or purchase decisions not entirely aligned with the purchase or production decisions of supply chain partners. Potential intervention points are represented for each of the market actors.

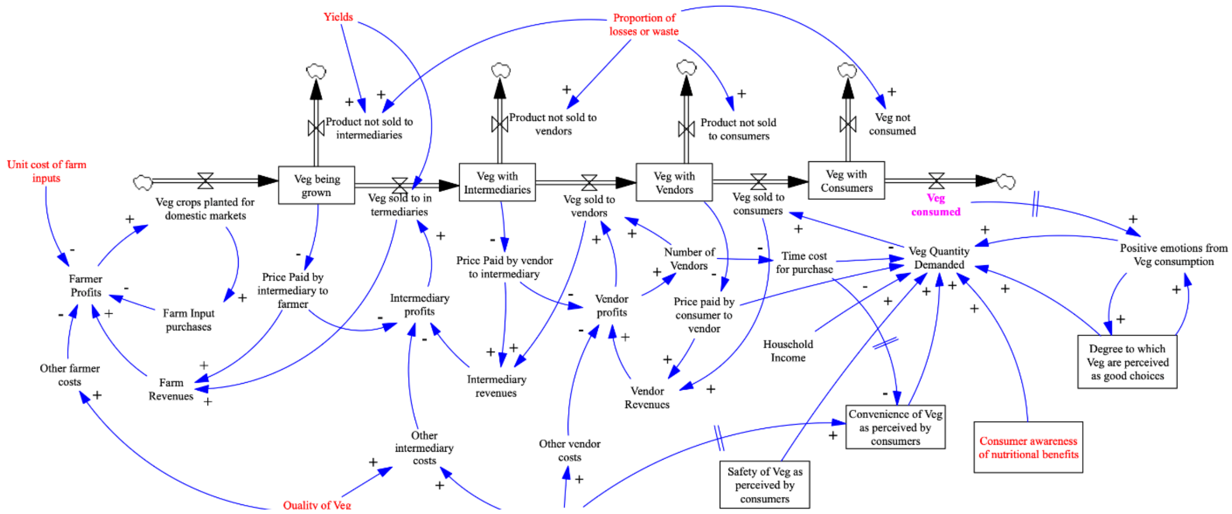
The model is designed to replicate the observed limited growth in vegetable consumption per capita from 2000 to 2015. The current model version represents 2015 observed consumption levels in "dynamic equilibrium" beginning in 2018 with unchanged market or promotion conditions, then examines the impacts of changes to factors that would affect consumption. The model represents five years (with a weekly time unit of observation) starting with 2018. Because relevant information is most available in the Kenya-based literature for GLV, the current model focuses only on a single vegetable product that is representative of GLV.

In the next section we present data organised around the two specific objectives first and then discuss the relevance and actionability of the information to programmes.

PROJECT FINDINGS

OBJECTIVE 1. CHARACTERISE THE DEMAND AND SUPPLY SIDE LINKAGES IN F&V VALUE CHAIN

The main outcome of the September workshop was to identify the linkages and pathways for the low consumption of vegetables in Nairobi, to be visualised as a causal loop diagram (Figure 2). This was completed by first identifying the most salient factors (incentives, influences, causes) affecting vegetable consumption (Table 1). Then participants were asked characterise affordability, desirability, and availability of vegetables in Nairobi by identifying defining each outcome (e.g., desirability), how it would be measured, and factors that affect this outcome. Finally, participants were asked about the type of interventions that could improve consumption; 22 interventions across the value chain were mentioned (Table 2).



Note: Boxes indicate “stocks” (inventories of products or current perceptions), double arrows indicate flows (of physical product), blue arrows indicate causal linkages among two variables, + and – indicate the nature of linkages between two variables. A '+' indicates that changes in the causal variable result in changes of the same direction in the target variable, and a '-' indicates that changes in the causal variable result in changes of the opposite direction in the target variable. Feedback processes are shown when variables are linked in a loop. Red variables indicate interventions analysed with the quantitative SD model.

Table 1. Summary of Factors Stakeholders Identified as Affecting Vegetable Consumption in Nairobi during September Workshop

Factors affecting vegetable consumption	Group 1	Group 2	Group 3	Group 4	Comments, key words	Mentions
Affordability	+	+	+	+		4
Food safety / hygiene	+	+	+	+	Implementation needed (policy), pesticides, contaminants	4
Seasonality		-	-	-		3
Cultural norms	-	-	-		Stereotyping of some foods, food imaging	3
Location of purchase			?	?	Various vendors	2
Education			+	+		2
Nutrition knowledge		+	+		Education, curriculum	2
Satiety (filling the stomach)	-		-			2
Convenience			+	+	Time for prep, access	2
Government regulation / policies			+	+	"Cess" fees	2
Supply chain function (efficacy, fairness, certainty)	+		+		Cartels, "long SC"	2
Availability	+			+	Variety also important	2

Factors affecting vegetable consumption	Group 1	Group 2	Group 3	Group 4	Comments, key words	Mentions
Publicity (promotion)	+	+		+		2
Presentation by the vendor	+			+	Point of sale	2
Climate (change)	-			-		2
Accessibility	+	+				2
Perishability	-	-				2
Knowledge of preparation	+	+			Use	2

NOTE: Link polarity indicated by '+' indicates that more of 'factor' means more consumption of vegetables; - indicates that more of 'factor' means less consumption of vegetables. For example, Increased affordability means greater consumption of vegetables, but increased perishability means decreased consumption of vegetables. Factors can refer to incentives, influences, or causes. An empty box means that the factor was not mentioned by the group and(or) they did not list any key words or other comments.

A wide range of factors were mentioned only once by workshop participants, relating to affordability (household income, occupation, household size, and prices), desirability (preference, awareness, media, health-consciousness of consumer, social influence and consumer aspirations, maternal employment, eating out, and decision-making at point of purchase), and availability (production capacity and costs, input availability and costs, seed varieties, adoption of new varieties, farmer know-how, farmer knowledge of market, post-harvest loss, storage capacity, value add opportunities, export market, support for business development, and development partnerships). These factors were also assigned link polarities.

As a follow-on from the first workshop, GAIN staff ranked the potential interventions to set priorities for inclusion in the model itself. The staff were asked to rank these interventions according to their feasibility based on GAIN's strategic mission, possible partnerships, and capacity to implement. The resulting rankings are shown in Table 2.

Table 2. Scenarios That Could Be Analysed with the Quantitative Model based on ranking by GAIN Staff

<u>Demand-focused Interventions</u> Improve quality* Improve safety and hygiene Improve convenience Reduce time cost for purchase Improve awareness of benefits Improve product positioning at point of sale Improve information and encouragement by vendor at point of sale Improve the perception of consumption as a "good choice" Increase incomes available for purchase	<u>Farmer-focused Interventions</u> Increase yields Reduce perishability at the farm Lower farm input costs Reduce farm production losses Increase farm input availability (if limiting) Improve quality*
<u>Intermediary-focused Interventions</u> Reduce perishability for the intermediary Lower intermediary variable costs	<u>Vendor-focused Interventions</u> Reduce perishability for the vendor Lower vendor variable costs

Improve quality*	Improve quality* Increase the number of vendors (assumed to occur with increased profitability)

* Likely involves changes throughout the value chain.

OBJECTIVE 2. DEVELOP A QUANTITATIVE SYSTEMS MODEL TO REPRESENT THE VEGETABLE VALUE CHAIN AND EVALUATE PROPOSED INTERVENTIONS.

The April workshop aimed to solicit additional input from participants on the responsiveness of value chain actors to various priority interventions represented in the quantitative model, and on how quickly these changes would be made by the actors. Participants ranked up to 11 interventions. The rankings are captured in Tables 3 and 4.

The top three consumer-oriented interventions identified by the workshop participants were:

- Improving awareness of nutritional benefits
- Improving quality
- Improving convenience

The top three value-chain priorities identified by the workshop participants were:

- Lowering farm input costs
- Reducing perishability (post-production) at the farm
- Increasing yields

Stakeholders noted that consumption changes would be more responsive to changes in quality, convenience, and time cost (Table 3) and that consumer responses would be fastest for changes in convenience, quality, and vendor encouragement at the point of sale. The volume of product marketed by other value chain actors was described as moderate to highly responsive to changes in profitability (i.e., more would be produced if profits were higher). The degree to which prices charged by intermediaries and vendors would be modified in response to demand changes was also described as moderate to high, but the ability to change prices charged was assessed as low for farmers. Costs for actors in the value chain were assessed as not very responsive to volumes marketed (i.e., there are limited economies (or diseconomies) of scale in vegetable marketing in Nairobi).

Table 3. Consumer-focused Priority Interventions to Increase Vegetable Consumption Indicated by Stakeholder Participants in the April Workshop

Potential Intervention	Priority Category (Number of responses)			Weighted Sum[a]
	First Priority	Second Priority	Third Priority	
Improve quality (may require full value chain)	2	2	1	11
Improve safety and hygiene (may require full value chain)			2	2
Improve convenience	2			6
Reduce time cost for acquisition (more vendors)				0
Improve awareness of nutritional benefits	3	2	1	14
Improve perceptions of vegetables as "good choice"	1	1		5
Increase incomes for purchase		1	1	3
Improve product positioning at point of sale		1	1	3
Improve information and encouragement of vendor at point of sale		1	1	3

[a] Weighted sum is calculated using the priority as weights: First priority = 3, Second priority = 2, and Third Priority = 1. Shaded rows indicate top three ranked interventions.

Table 4. Value-Chain Focused Priority Interventions to Increase Vegetable Consumption Indicated by Stakeholder Participants in the April Workshop

Potential Intervention	Priority Category (Number of responses)			Weighted Sum[a]
	First Priority	Second Priority	Third Priority	
Increase yields	1	1	2	7
Reduce perishability at farm	2		2	8
Lower farm input costs (perhaps subsidies)	2	2		10
Reduce farm production losses		1	1	3
Increase farm input availability if limiting	1			3
Reduce perishability for intermediaries		1	2	4
Lower intermediary costs (perhaps subsidies)		1		2
Reduce vendor perishability	1	2		7
Lower vendor costs (perhaps subsidies)	1		1	4
Increase vendors				0

[a] Weighted sum is calculated using the priority as weights: First priority = 3, Second priority = 2, and Third Priority = 1. Shaded rows indicate top three ranked interventions.

Following the April workshop, we conducted subsequent discussions with three individual experts to identify the potential impacts of interventions. Those discussions are summarised in Tables 5a and 5b.

Table 5a. Summary of Characteristics of Priority Potential Interventions to Increase Vegetable Consumption and Subsequent Consultation with Subject-Matter Experts

Intervention Characteristic	Consumer-Focused Interventions		
	Improve Awareness of Nutritional Benefits	Improve Quality of Vegetables	Improve Convenience
Measurable indicator	Number of servings, portion sizes, diversity (adding new vegetables, not just more of same)	Colour, shape, texture, and aroma for vegetables (ripeness, discolouration); for leafy greens, sturdy leaves and fresh appearance	For greens, washing, chopping, and bagging at point of sale
Degree of change possible	Varies with type of awareness, from limited to moderate, but limited information is available for specific actions	Limited by already high quality, price discounts for lower-quality produce that benefit price-sensitive customers	Limited by the high proportion of vendors already offering this service at vendors other than supermarkets
Actions required by value chain actors or external partners	Programme efforts to increase awareness	Limited for small potential changes	Limited for possible changes
Impact on value chain costs	Limited direct impacts	Limited for small potential changes	Limited for possible changes
Time required to implement	Potentially lengthy	Potentially lengthy with value chain investments required	Short-term change possible
Subsequent comments from subject matter experts	Awareness of general nutritional benefits is already high, so awareness efforts would need to focus on other aspects. Stepped progress to meet goals may be appropriate strategy	Price-sensitive customers have lower expectations for quality (price primary factor)	Plastic bags formerly used for 'packaging' now banned. What are alternatives? Better access to clean water and more efficient chopping technology may help vendors

Table 5b. Summary of Characteristics of Priority Potential Value Chain Interventions and Subsequent Consultation with Subject-Matter Experts

Intervention Characteristic	Value-Chain Focused Interventions		
	Lower Farm Input Costs	**Reduce Farm Perishability**	**Increase Yields**
Measurable indicator	Unit costs of production	Proportion of production harvested not suitable for sale	Production per acre
Degree of change possible	Potential unit cost reductions of 30-50%	Could be reduced to 10% (compared to currently assumed 15%)	100% increase
Actions required by value chain actors or external partners	Farmer training in Good Agricultural Practices (GAP); reductions in taxes on farm inputs	Farmer training in GAP; improved storage, continuous market access (especially in rains)	Farmer training in GAP; increased investment and input use
Impact on value chain costs	See above	Increases, varies with intervention	May reduce unit costs of production although total costs are higher
Time required to implement	Potentially lengthy for farmer training	Potentially lengthy for farmer training and infrastructure development	Potentially lengthy for farmer training and infrastructure development
Subsequent comments from subject matter experts	Kalgudi platform[a] for mangoes in India provides an example of how improved coordination and transparency can lower costs and improve yields through more appropriate input use	Perishability can be linked to yields but is treated separately here	Yields can be related to perishability but are treated separately here

[a] Kalgudi is a digital convergence platform. It empowers farmers and micro entrepreneurs with the relevant information, connects them with relevant businesses for inputs, services and outputs with artificial intelligence-based aggregations, and helps food producers sell directly to consumers with complete traceability.

Specification of Model Scenarios for Analysis of Priority Interventions

Based on information from the April workshop and subsequent discussions with individual experts, we developed scenarios (sets of assumptions) to be used for analysis with the systems simulation model and the range of simulated impacts. To facilitate comparison among scenarios, the assumptions about changes were typically expressed in terms of percentage changes from the current situation (e.g., a 10% increase in the proportion of the population that is aware of relevant nutritional benefits of vegetable consumption.) Changes in relevant value-chain costs associated with implementation of the intervention were also expressed in terms of percentage changes from the current values. All interventions were assumed to implemented (and be fully effective) as of May 2020. This assumed no one-time costs (investments), time delays, or issues with implementation, which is consistent with the focus of the model but represents a best-case scenario in terms of impacts vis-à-vis more realistic programme implementation challenges. The model focused on vegetable consumption, because information needed for assumptions was more readily available, and initial values of daily vegetable consumption per capita were based on the Global Dietary

Database. A "Dynamic Equilibrium" scenario was used to represent the status quo at current and stagnant consumption levels. The model simulated weekly results for 260 weeks (5 years) beginning in January 2020.

The potential for improvements in consumer-facing interventions was generally small, according to the opinions of the workshop participants (Table 6a), in large measure because general awareness of nutritional benefits, adequate quality, and appropriate convenience were already characteristics of the Nairobi market—although these may not characterise other urban centres or rural areas in Kenya. The potential impact of the value-chain interventions (all at the farm level) was deemed to be larger, so assumed percentage changes in costs of production, perishability, and yields are larger than assumed percentage changes for consumer-facing interventions (Table 6b). A "Combined" scenario that included all interventions except for the decrease in perishability at the farm was included to assess the maximum potential for improvement in vegetable consumption and possible synergies among interventions (Table 7).

Table 6a. Changes in Simulation Model Parameters to Implement Consumer-Focused Intervention Scenarios and Related Sensitivity Analyses

Simulation Model Changes	Consumer-Focused Interventions		
	Improve Awareness of Nutritional Benefits	Improve Quality of Vegetables	Improve Convenience
Parameters Modified for Scenario	10% increase in awareness No change in value-chain costs	5% increase in quality of products 5% increase in costs for all value chain actors	5% increase in convenience of products sold by vendor 2.5% increase in vendor costs
Range of value for sensitivity analysis	None	0 to 10% for increase in value-chain costs	0 to 5% for increase in vendor costs

Table 6b. Changes in Simulation Model Parameters to Implement Value-Chain Focused Intervention Scenarios and Related Sensitivity Analyses

Simulation Model Changes	Value-Chain Focused Interventions		
	Lower Farm Input Costs	Reduce Farm Perishability	Increase Yields
Parameters Modified for Scenario	30% decrease in unit variable costs of production at the farm level	33% reduction in post-harvest perishability at the farm level (10% losses rather than 15% losses) 10% increase in unit variable costs of production at the farm-level	50% increase in yields at the farm level 5% increase in unit variable costs of production at the farm level
Range of value for sensitivity analysis	10 to 50% reduction in unit variable costs of production at the farm level	5 to 20% increase in unit variable costs of production at the farm level	5% decrease to 10% increase in unit variable costs of production at the farm level

Table 7. Range of Simulated Impacts (g/day) of Interventions on 2024 Vegetable Consumption, N=200 Random Sets of Parameter Values

Simulated Outcome	Increase Awareness	Increase Quality	Increase Convenience	Decrease Farm Costs	Decrease Farm Perishability	Increase Farm Yields	Combined Scenario[a]
Minimum value	131.6	132.3	134.8	131.2	125.1	121.6	170.1
Median value	136.9	140.1	143.0	132.8	130.5	171.3	198.7
90th percentile value	149.8	155.9	159.1	140.0	131.2	194.4	207.5
Maximum value	169.6	180.4	186.6	148.4	131.2	205.6	208.9

NOTE: Values represent average daily per capita vegetable consumption, g/day. Consumption in dynamic equilibrium is 131.2 g/person/day.[a] The combined scenario includes all interventions other than a decrease in on-farm perishability.

OBJECTIVE 3. ASSESS THE EXTENT TO WHICH A PARTICIPATORY SYSTEMS MODELLING COULD PROVIDE RELEVANT AND ACTIONABLE INFORMATION IN THIS CONTEXT.

In this section we discuss the key programmatic lessons learned from this participatory systems modelling work, followed by a more general discussion of the programmatic relevance of the model results.

Programmatic Lesson 1. Existing GAIN data sources and expert input can be used to understand causal linkages.

Value chain assessments for GLV and tomatoes completed by GAIN (24) were useful to understand the local value chain's structure, its actors, and their actions. Expert stakeholders (farmers, traders) in the workshops offered rich detail on the how actors might respond to certain actions, which was needed to define the causal loop diagram.

Unfortunately, GAIN did not have an archive of consumer-relevant information on the drivers of vegetable consumption. Local experts also had a very limited understanding of the purchase drivers for vegetables among lower-middle-income Nairobi consumers, with a skew towards 'awareness of nutrition' as a key consumer preference criterion. Although stakeholders identified cultural norms as a key factor, stakeholders were not able to characterise this domain using variables or metrics. There is some evidence of potentially unfavourable perceptions among peri-urban consumers: vegetables are perceived as a 'low status food', a type of food one would not typically serve guests (18). In the future, relatively poor understanding of causal linkages on the demand side could be addressed in the workshops, through role-playing activities to identify key variables and their parameters, or by conducting qualitative research prior to the group modelling process (see Box 1).

Overall, expert knowledge is necessary to develop the conceptual model of the value chain, which captures the feedback loops and key system linkages among the various actors. Expert input on the supply side is useful for prioritising proposed interventions and facilitating quantitative systems assessment of intervention priorities. The conceptual model represented the important elements of consumer demand, although the causal relationships are less well articulated and require further research to elucidate possible causal pathways (see example in Box 1). Drivers of consumer purchasing decisions can be explored empirically with two techniques from consumer economics: choice experiments (29) and experimental auctions (30). As a result of the current state of knowledge, the impacts of product attributes important for consumers are represented in the SD model as relative to an initial reference value, and the impacts of proportional changes from that reference value were assumed for the interventions. Additional information on consumer preferences and responses to changes in these factors—as proposed above—would be of considerable usefulness for future assessment of interventions.

Programmatic Lesson 2. Empirical data from the published literature can be used to produce a quantitative model.

Development of an SD model requires empirical evidence about the nature and magnitude of causal linkages. One example would be how quality affects the amount of F&V purchased by households. Modellers often rely on published data in the literature to inform the representations of these relationships in the model, but when lacking this information, the representations can be developed from expert opinions, stakeholder perceptions, or other evidence from qualitative assessments. When empirical evidence is known only as a range of possible values (i.e., with uncertainty), it is relevant to use sensitivity analysis to assess the range of possible outcomes. Sensitivity analysis is the systematic assessment of how changes in assumptions (e.g., specific parameter values) affect the outputs from a simulation model. In our context, the sensitivity analyses were designed to assess whether the simulated impacts of proposed interventions were sensitive to a range of values for uncertain parameters.

There were insufficient empirical data on several of the causal relationships represented in the model, especially the consumer side of the model (e.g., how 'quality' improvements would be likely to affect consumption, all other things being equal). There was substantial information on consumer preferences for certain attributes. However, most of the published evidence was limited to descriptive, rather than causal, drivers of vegetable consumption, such as ranking of the importance of attributes such as 'quality' (freshness) and 'safety/hygiene' or the degree of current awareness, such as for the 'nutritional health benefits of F&V consumption'. This uncertainty in empirical understanding was assessed with sensitivity analyses, which suggested large possible ranges for improvement in F&V consumption. However, in the case of the Nairobi market, the impacts of this uncertainty about demand responsiveness were small because the experts assessed that there was not much scope for improvement in these factors given current product characteristics (at least for quality, convenience, and awareness of nutritional benefits). This is one factor underlying the limited impact on consumption—the scenarios analysed assumed there was limited potential to do so.

PROGRAMMATIC RELEVANCE OF THE MODEL RESULTS

There are various outcomes from this project that are relevant for programming purposes. We describe those here and then share how this information was used by GAIN.

First, the model showed the larger potential impact in this context of upstream (farm-level) interventions as compared to further efforts to raise nutritional awareness, which is often the default demand-side intervention in the public health sector. Other investments in demand appear to be necessary, such as leveraging existing preferences for safe vegetables and possibly information about portion sizes. From an economic perspective, demand enhancement has some self-limiting properties if not combined with supply-side interventions. In East Africa, most countries do not produce sufficient vegetables to meet recommendations (9). Increasing demand by the desired amount would increase prices, which would offset some of the positive impacts—unless the supply side can respond and produce those higher quantities at the same costs as before, something we cannot estimate given the current data. At the very least, promotion should be adjusted across growing cycles, with promotion peaking during high seasonal availability. The combined scenario model had the highest simulated impact, thus suggesting a potential appropriateness for linking demand- and supply-side interventions.

Second, the SD model shows that not all parts of the value chain are equally important, an assumption that is applied to the VCA. Interventions in certain stages of the value chain are more important for achieving nutritional outcomes. For example, reductions in food loss and waste are often seen as priorities, but our analyses suggest reductions in food loss in the middle of the value chain would have a relatively modest impact on consumption. It is likely that when losses are minimised in wholesaling or retailing, these value chain actors do not need as much inventory, translating to fewer orders. Also, technology that keeps food fresher would provide little incentive to sellers to lower their prices to sell perishable items.

Third, the participatory systems modelling approach builds on the VCA and adds critical information to prioritise actions and resource investments. While the SD model and VCA might identify similar classes of interventions, given the literature and data sources used, the

SD model offered more: it provided estimates of the potential impacts on the nutrition outcome of interest and a time period for when those changes might be achieved.

In the final quarter of 2020, GAIN used the outputs of this project to plan for a 5-year investment in the vegetable value chain in Kenya. We identified the GAIN programmes across the six intervention classes that could be deployed, including how to address the issue of value chain coordination. For improving agricultural yields, an area outside of GAIN's expertise, we cooperated with other organisations through strategic partnerships. The participatory systems modelling process was useful for planning purposes, but the current form of the model cannot inform programme design. A subsequent programme assessment phase will help fill the data gaps identified in this report, and the assessment data, as well as programme monitoring data, will help refine the model. To better represent the appropriate modalities for implementation, including the potential need for improved coordination among value-chain participants, additional participatory modelling processes are also needed. As the model is improved and refined, it will be used to support decision-making and resource allocation across the five-year programme.

BOX 1. IDENTIFYING CONSUMER BEHAVIOURS CAUSALLY RELATED WITH QUALITY OF GREEN LEAFY VEGETABLES

Consumers' evaluation of quality is usually done through visual inspection of the product at point of sale. The attribute 'freshness', might be described as 'leaf integrity/wilting' and 'deep green colour'. Below is a hypothetical question and response guide to identify variables and parameters of the model.

Question	Consumer Response	What the answer might reveal
How do you know the freshness of green leafy vegetables?	Visual inspection of product.	Establishes a metric for freshness
What visual elements signal freshness to you?	Normally: wilting of leaves, colour of the leaves. Sometimes: strength of stems.	Identify attributes linked to freshness
I have some pictures of spinach. They range from no wilted leaves to very wilted leaves. Can you tell me at which point you would not buy the product and why?	Respondent is shown pictures of spinach of varying quality from very fresh to poor quality (e.g., ready to throw out).	Identify a threshold effect by specifying at which point is purchase (response) not considered. Establishes parameters of freshness
Of the products you would not buy because it not fresh, would a price discount make you more willing to buy any of these? If yes, for the ones you would buy at lower prices, can you specify using percentages how much lower quality is this product from the (threshold product)? Would you prepare this product any differently?	I would buy at 50% discount. I would pay this lower price but only for 20% lower quality compared to threshold. I would prepare the less fresh leaves in boiled in stew (vs. sauteed side dish, which requires good quality).	Identify other variables that affect consumer purchase to be considered in a causal loop diagram. Determine the sensitivity of response.
Of the pictures you said you'd buy, would you buy more spinach if it was the freshest spinach?	No, I would still only buy what I need. I might be willing to pay more for a fresher product, but that depends on my grocery budget and how much my family would enjoy a fresher-tasting product.	Identify a ceiling effect. Identify any other consumer response (e.g., food budget, enjoyment factor)

CONCLUSION

The utility of participatory systems modelling lies in its ability to capture the complexity of value chains, informed through a systems perspective, and allow the use of various data sources, including stakeholder knowledge, to generate a simulation model to inform programme planning efforts. The main contributions of the model development process applied here to the case of vegetables in Nairobi, Kenya were that it:

1) Increases awareness of the complex linkages and pathways that play a role in the current low and stagnant pattern of vegetable consumption in Nairobi;
2) Improves awareness of the need for specificity in the definitions of key concepts that influence vegetable consumption, which may facilitate future related studies;
3) Identifies the general approaches (classes of interventions) likely to have the largest impact on vegetable consumption over a five-year time horizon, which can facilitate additional specific analyses of programmatic alternatives to implement them; and
4) Consolidates data from existing sources in a single logical framework and facilitates the identification of future data needs and research questions.

These advantages notwithstanding, future iterations of this project in Kenya or elsewhere will need to invest in further development of the model and in refining the participatory process. The current process produces a high-level model, and investments are needed to improve the model's predictive ability. Much of the information necessary for the development of the quantitative model was not readily available from previous sources. Although stakeholders provided their assessments, and uncertainty in the information was evaluated with the simulation model, the relatively large ranges of outcomes indicated by the analyses suggest that allocating resources to improve knowledge on causal linkages and response parameters would be valuable. Further work may also be needed to assess alternative interventions (e.g., improved safety and hygiene, or targeted income transfers) not listed as priorities by the stakeholders. A more comprehensive assessment of other intervention packages may also be needed, given that stakeholder judgments were limited to the scope of the necessary analyses and not the full complexity of the interactions in the vegetable value chain.

In Kenya, specifically, there are three main areas that merit further knowledge development. Additional information on cost structures and prices throughout the value chain (see 25) and their changes over time and in response to interventions would allow improved representation of core business performance metrics and likely behaviours. Information on the responsiveness of consumers to changes in factors such as quality, convenience, and hygiene is very limited; prior studies often include ranking of the importance of these factors but not a linkage to their impacts on consumption. Finally, the potential for change in each of the factors and associated costs would better inform scenario development and allow more refined use of the value-chain linkages in the current simulation model. These data could be used to refine the analyses—to narrow the range of possible outcomes currently due to data uncertainty. Finally, the nature of supply chain actors, responses to changing market conditions, cost structures, and consumer preferences is likely to differ by location or target population. The current model is for Nairobi, so it would likely require some modification to represent supply chains for vegetables in smaller Kenyan cities or for different target consumers (e.g., rural consumers). These relevant differences could be identified through a participatory process like that used for this project, one that could nonetheless draw upon the lessons learnt from this pilot effort.

Further refinement to the participatory process, either in the specific workshop activities or the sequencing of activities, is needed to better describe the causal relationships. The causal loop diagram builds from actors' existing mental models, so biases and preferences are evident in both the system structure and in prioritising interventions. Assessing other potential interventions through the SD model, even if not mentioned by stakeholders, might be one way to mitigate biases. Also, the workshops did not include all relevant stakeholders, such as informal retailers or consumers. Involving these key stakeholders through specific activities during workshops or conducting appropriate retail-consumer studies would help in identifying causal pathways and inform key elements of the model structure and its parameters.

Despite these areas for improvement, by addressing knowledge gaps and refining the participatory process, the participatory systems modelling approach has proved both useful and relevant for strategic planning purposes and can be deployed in development organisations such as GAIN.

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