Assessing the Impacts of Three Potential Interventions on Fruit and Vegetable Consumption in Urban Kenya Using Participatory Systems Modeling

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Abstract

Average fruit and vegetable consumption in Kenya is estimated to be well below the 400 grams per person per day recommended by the World Health Organization (WHO) and has not increased since 2000. The low and stagnant consumption of fruits and vegetables has been attributed to many factors, and multiple interventions have been implemented or proposed to address this issue. This study uses a participatory stakeholder process to identify priority interventions and to develop a quantitative systems model of the value chain to assess their potential impacts on fruit and vegetable consumption during 2020 to 2024. This process involved convening two workshops (in September 2019 and April 2020) with a diverse group of fruit and vegetable value chain stakeholders. The SD model provides information on the impact on consumption during 2020 to 2024 of three proposed interventions assuming mean parameter values and with assessment of uncertainty using 200 simulations with randomized parameter values. Stakeholders adopted a supply-chain perspective on the problem and identified three interventions with potential to increase consumption: increase consumer awareness of health benefits, reduce post-harvest losses on farm and increasing yields of farm production. Increasing consumer awareness would increase vegetable consumption by relatively modest amounts by 2024 (5 grams/person/day from a base of 131 grams/person/day) under mean assumed value of value chain response parameters. However, stochastic analysis of alternative values of these response parameters resulted in a range of increases from near 0 grams/person/day to nearly 40 grams/person/day. Reducing perishability was simulated to reduce consumption due to the higher costs required to reduce losses. Increasing farm yields had the largest impact on consumption at assumed parameter values (about 40 grams/person/day), but also the largest range of uncertainty under stochastic analyses. Moreover, increasing farm yields would have a large negative impact on farm profits, which could undermine efforts to implement this intervention. The uncertainty of outcomes (ranges of values) in the stochastic scenarios is primarily due to uncertainty in the responsiveness of consumption to changes in awareness, the magnitude of any cost changes and the price elasticity of demand. This study is one of the first to apply GMB and simulation modeling to issues of public health nutrition.

Key words: nutrition, group model building, fruit and vegetable consumption, Kenya

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1 Background and Objectives

1.1 Background on Fruit and Vegetable Consumption in Kenya

Fruit and vegetable (F&V) consumption is considered an important component of a healthy diet with numerous documented and hypothesized health benefits (Ruel et al., 2015; Micha et al., 2015). In urban Kenya, F&V consumption is below the amount recommended by the World Health Organization (WHO) of 400g per day for all educational attainment levels reported in the Global Dietary Database (GDD, https://www.globaldietarydatabase.org; Figure 1). Consumption of both fruits and vegetables in Kenya is also considerably below the 'optimal' levels proposed by Micha et al. (2015) of 300 g/day and 400 g/day, respectively. Moreover, there has been essentially no change in per capita consumption of fruits and vegetables on average in Kenya during the years 2000 to 2015 based on data from the GDD.

The low and stagnant levels of F&V consumption in Kenya provide the motivation for an evaluation of interventions that could modify the observed outcomes during 2000 to 2015 to achieve consumption increases that approach WHO standards and have the potential for meaningful impacts on human health and well-being. Previous literature has identified diverse factors likely to affect F&V consumption both more generally and specifically in the Kenyan context (e.g., Obel-Lawson, 2006; Okello et al. 2015). These factors typically fall into one of three general categories. *Availability* comprises production and post-production supply chain activities that facilitate product purchases by ultimate consumers. *Affordability* means that regular purchases of product are possible by consumers based on their incomes and product prices but could also include the time costs required for purchases. *Desirability* comprises a diverse set of influences that affect a consumer's willingness to purchase, including cultural influences, knowledge of both benefits and preparation, product quality, safety and hygiene, and emotional responses to food choices.

Although numerous factors have been identified as influencing consumption of fruits and vegetables in Kenya (e.g., Jaffee, 2003; Obel-Lawson, 2006; Lagerkvist et al., 2011; Okello et al. 2015; Pengpid et al., 2018), this information alone is generally not sufficient to assess interventions to increase F&V consumption. One limitation is that much of the available information about consumption determinants is qualitative, without a specific measurable relationship between the determinants and actual consumption levels. Another is that even when determinants are better understood (quantitatively) the development of effective interventions does not always follow directly from this information, given a multiplicity of possible intervention approaches designed to influence the determinants. Finally, interactions among decision-makers throughout the F&V supply chain have the potential to enhance or limit the effectiveness of interventions to increase consumption.

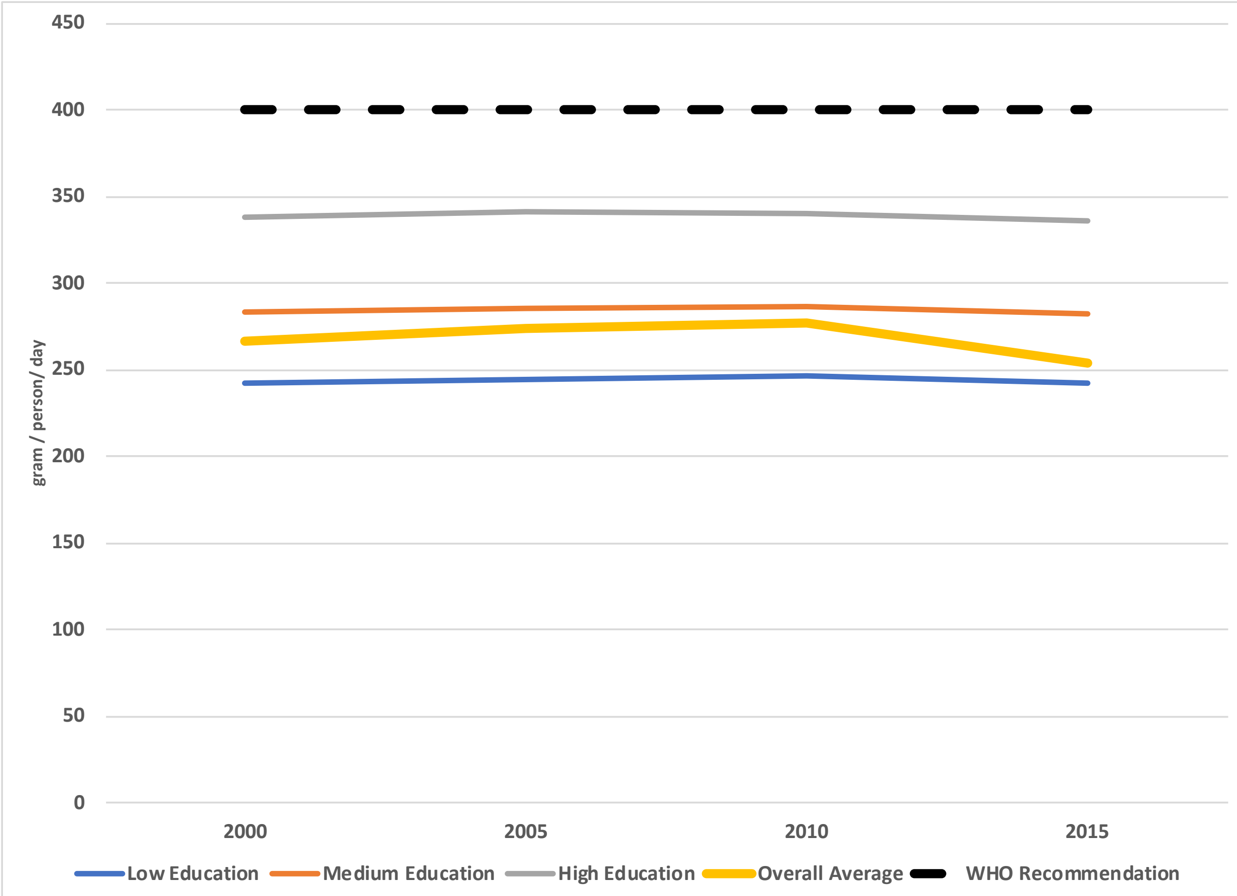

Figure 1. Reference Mode: Per Capita Consumption of Fruits and Vegetables, Daily Average by Educational Attainment, Kenya, 2000 to 2015.

Source: Global Dietary Database.

The current state of knowledge thus constrains the identification and implementation of priority interventions to increase F&V consumption in Kenya. To the best of our knowledge, there has been no systematic comparative evaluation of the wide range of intervention possibilities in this context. Such a comparative evaluation of interventions would be useful to support priority setting for organizations with a mandate to increase F&V consumption and is the overarching motivation for this study.

1.2 Study Objectives

The overall objective of this study is to evaluate interventions to increase F&V consumption in Kenya, with the following specific sub-objectives

1) Implementation of two workshops with key stakeholders in the Kenya F&V supply chain to Identify hypothesized causal pathways that result in lower-than-desired F&V consumption and potential interventions to increase that consumption;

2) Development of quantitative system dynamics model to represent system structural constraints and proposed interventions based on pre-workshop preparation, the stakeholder workshop, and review of relevant literature;
3) *Ex ante* of the effectiveness of three interventions commonly proposed by international organizations: increasing consumer awareness of the health benefits, reducing perishability in the value chain and increasing farm yield (production) to increase availability

This study combines information from the Group Model Building (GMB) process with a review of information from the literature to assess intervention options, with a focus on how they would increase average F&V consumption during the five years following assumed implementation. Although GMB methods have been applied to related issues (e.g., Guariguata et al. 2020), this effort is one of the few that has quantified the potential impact of specific interventions to affect nutritional outcomes.

2 Methods

2.1 Group Model Building Process with F&V Supply Chain Stakeholders

The underlying purposes for this workshop was to solicit input from relevant stakeholder about the factors and linkages that have limited increases in F&V consumption in Nairobi, and to increase awareness of the complexity of supply chain interactions that could limit the ability to effect change. This workshop was held in Nairobi as two half-day sessions on 12-13 September 2019 and included 16 participants from different perspectives on the Kenya supply chain for fruits and vegetables. Consistent with the approach described in Vennix (1996) and Rouwette and Franco (2015), participants were led with a series of scripts to identify factors affecting a low and stagnant levels of F&V consumption as the reference mode behavior through 2025. During the introduction, participants were provided with information about the overall process for the project, the structure of the workshop, an operational definition for fruits and vegetables and an illustrative listing of F&V supply chain stakeholders.

The second half day session began with a summary of the factors that participants identified as influencing consumption of fruits and vegetables in Nairobi and their definitions and metrics for affordability, availability and desirability. The initial systems diagram based on stakeholder input was presented and discussed to identify and necessary corrections or additions of factors or linkages (Figure 2). A number of feedback processes with the potential to enhance or limit increases in F&V consumption were identified (a qualitative analysis) to illustrate the potential insights from a systems analysis. Participants then identified priority interventions to increase F&V consumption, that is, to modify the “reference mode” behavior to more desirable outcomes.

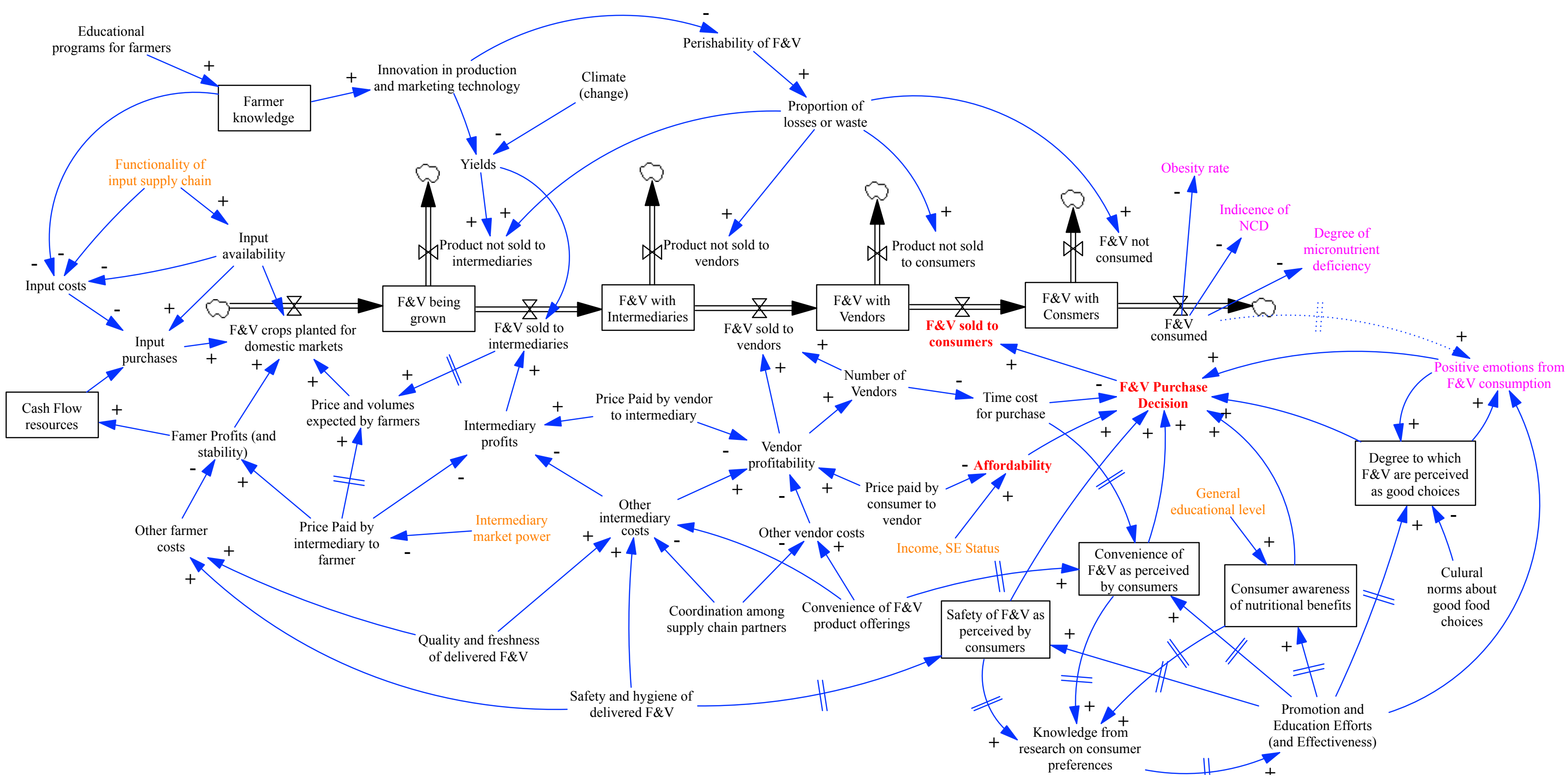

Figure 2. Initial Systems Mapping Based on Day 1 Exercises from September 2019 Stakeholder Workshop

NOTE: Red variables are key outcomes, Orange are exogenous factors, and pink variables are ultimate health outcomes of interest.

2.2 Quantitative Model Development

Based on the input from stakeholders from the September workshop, an SD model was developed for quantitative assessment of proposed interventions. The structure for the supply chain components of the model (farm production, intermediaries[3], and vendors) is based on the supply chain formulation in Sterman (2000), modified in this case to reflect multiple linked supply chain actors for F&V products. 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 product by intermediaries, vendors and consumers.

Although in some supply chain models, perfect coordination is assumed (orders are coordinated throughout all levels of the supply chain), we do not assume that the F&V 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. Relevant literature on F&V supply chains in Kenya and related to consumer behavior was used to develop specific quantitative relationships among the variables identified in the stakeholder workshop.

The initial model is designed to replicate the reference mode of observed limited growth in F&V consumption per capita. 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. The current model focuses only on a single “generic” product that is more representative of leafy greens. *A detailed model description is available as a complement to this paper.*

A second workshop was held with the same participants in April 2020 (via Zoom due to Covid restrictions) to present the structure of the quantitative SD model to stakeholders, to solicit suggested modifications and to refine the scenarios for quantitative analysis.

[3] *Intermediaries* are defined for the purposes of the model as the first buyer of 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.

2.3 Specification of Model Scenarios for Analysis of Priority Interventions

Based on information from the April workshop and subsequent discussions with individual experts, we summarized the potential impacts of interventions (Table 1) and developed scenarios (Table 2). These scenarios analyzed interventions that focused either on consumers or other value-chain participants (farmers or intermediaries). For this paper, we focus on three commonly-proposed interventions: increasing awareness of the health benefits of F&V consumption, reducing perishability in the supply chain and increasing vegetable yields. Each of these has been attempted to some extent previously in the Kenya F&V supply chain and are otherwise commonly proposed interventions to improve nutritional outcomes from food supply chains more generally (Ridoutt et al., 2019; Nicholson et al. 2021). To facilitate comparison among scenarios, the assumptions about changes are 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 F&V consumption. Changes in relevant value-chain costs associated with implementation of the intervention are also expressed in terms of percentage changes from the current values. All interventions are assumed to implemented (and are fully effective) as of May 2020. This assumes 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 program implementation challenges.

Table 1. Summary of Characteristics of Priority Potential Interventions to Increase Fruit and Vegetable Consumption Based on April 2020 Workshop and Subsequent Consultation with Subject-Matter Experts

Intervention Characteristic	Improve Awareness of Nutritional Benefits (Consumer Focus)	Reduce Farm Perishability (Farm Focus)	Increase Yields (Farm Focus)
Measurable indicator	Number of servings, portion sizes, diversity (adding new fruits and vegetables, not just more of same)	Proportion of production harvested not suitable for sale	Production per acre, kg/acre
Degree of change possible	Varies with type of awareness, from limited to moderate, but limited information is available for specific actions	Could be reduced to 10% (compared to currently assumed 15%)	100% increase
Actions required by supply chain actors or external partners	Program efforts to increase awareness	Farmer training in Good Agricultural Practices (GAP); improved storage, continuous market access (especially in rains)	Farmer training in Good Agricultural Practices (GAP); increased investment and input use
Impact on supply chain costs	Limited direct impacts	Increases, varies with intervention	May reduce unit costs of production although total costs are higher
Time required to implement	Potentially lengthy	Potentially lengthy for farmer training and infrastructure development	Potentially lengthy for farmer training and infrastructure development
Other comment	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	Perishability can be linked to yields but is treated separately here	Yields can be related to perishability but are treated separately here

Table 2. Changes in Simulation Model Parameters to Implement Intervention Scenarios and Related Sensitivity Analyses

Simulation Model Changes	Improve Awareness of Nutritional Benefits (Consumer Focus)	Reduce Farm Perishability (Farm Focus)	Increase Farm Yields (Farm Focus)
Parameters Modified for Scenario	10% increase in awareness No change in value-chain costs	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	None	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

3 Results

3.1 Results of Deterministic Intervention Scenarios

A first set of scenarios assessed the impacts of the three interventions at the mean estimated values key response parameters and thus represent the mean expected impact of the interventions. They also provide a starting point for discussion of stochastic scenarios when many parameters are assumed to uncertain. As discussed further below, alternative parameter assumptions will affect the degree to which any of the intervention can be effective, for which determining the distribution of values can be useful. The deterministic results indicate that increasing consumer awareness and increasing farm yields would increase vegetable consumption (Figure 2; Table 3). These two interventions show increases the continue during the five years simulated by the model. This pattern of ongoing increase results from the time required for value-chain participants to perceive and respond to relevant changes[4], and from a reinforcing feedback effect. This latter effect is based on the positive emotional response and reinforcement of F&V as good choices, both of which are assumed to be enhanced as vegetable consumption increases. Thus, initial increases from the intervention are maintained and enhanced by the emotional response processes of consumers.

Efforts to increase consumer awareness are often promoted as a means to improve the quality of diets (e.g., Poelman et al., 2019), but evaluations of their effectiveness have shown mixed results (Obel-Lawson, 2006; Rekhy and McConchie, 2014). The limited impact on F&V consumption from this intervention (an increase of less than 3 g/person/day) derives from the

[4] Although programs are assumed to be implemented instantaneously and immediately effective, the behavior of value-chain participants is assumed to require time for changes to occur.

GMB workshop consensus that most Nairobi consumers are already aware of the relevant health benefits (so that only small increases in awareness are possible) and that the responsiveness of F&V consumption to increased awareness is relatively low. The percentage change in consumption associated with a 1% change in awareness ('elasticity' value) is estimated as 0.6 based on stakeholder input.

Another commonly-proposed supply chain intervention is reduction of perishability (Tshirley and Ayieko, 2008; Gogo et al. 2017; Rodriguez, 2018), often with the goal of reducing costs due to product losses and also increasing product availability. Our scenario assumes a one-third reduction in losses of product from post-harvest farm inventories, from their currently estimated value of 15% to a value of 10%. To achieve this reduction in farm perishability a 10% increase in variable costs is assumed to be required, which reflects the potential costs of improved storage and farmer training. *This intervention is simulated to <u>reduce</u> daily per capita consumption of F&V*, for two principal reasons. First, although there is a reduction in product losses (and associated supply costs), the effect of smaller product losses on the unit cost is less than the assumed cost increase required to achieve it, so product prices increase. There is no shifting of the demand curve for F&V, so a higher price results in reduced consumption. A related effect occurs due to the assumptions made about inventory management by farmers, intermediaries and vendors. These value-chain actors typically place orders with their suppliers to meet expected demand with an expected amount of product loss. Farmers are assumed to make planting decisions consistent with meeting expected orders from intermediaries but also accounting for expected product losses. Smaller post-harvest product losses therefore imply that less production is needed to meet expected demand from intermediaries, which can have the effect of increasing unit variable costs of production if there are economies of scale in production as assumed for this analysis. The specific assumptions about behaviors and costs here could affect the simulated outcome of changes in perishability, so further, more specific assessments of such interventions are merited.

The intervention with the largest impact on simulated F&V consumption is for increased farm yields. By the end of 2024, this scenario suggests that daily per capita consumption could be increased by nearly one-third of 2020 amounts, by more than 40 g/person/day. This large change is due in part to the assumed size of the yield increase (50%), the relatively small increase in unit costs of production to assume this yield increase (5%) and the fact that the large increase in production from higher yields results in a 20% reduction in the farm price, which increases demand further down the supply chain. Prices initially fall throughout the supply chain, but then increase for vendors and consumers as the effects on demand from emotional benefits and making good choices further enhance demand. Although this intervention is the most effective for increasing consumption, it also *markedly lowers farm profitability* compared to the status quo, in part because farms are assumed not to have much as much ability to modify their prices in response to changes in supply and demand as intermediaries or vendors, per the April GMB workshop discussions.

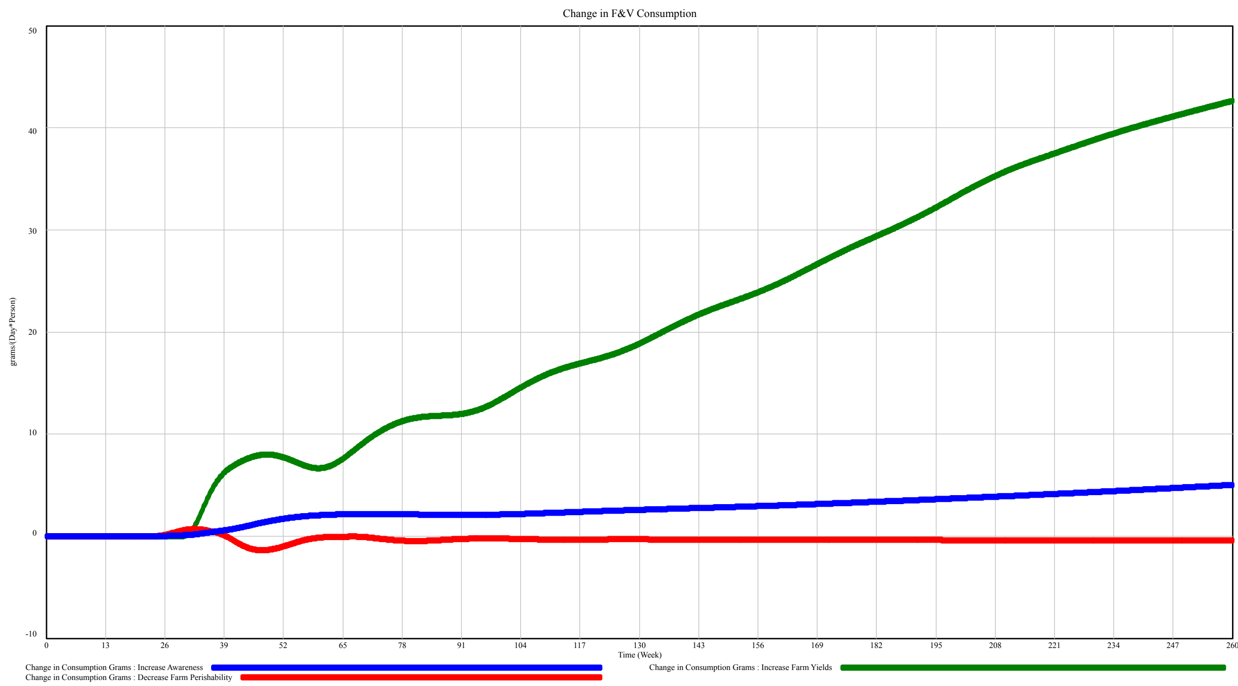

Figure 3. Simulated Changes in Daily Per Capita Vegetable Consumption Under Three Intervention Scenarios

Blue: Increase Consumer Awareness

Red: Reduce Farm Perishability

Green: Increase Farm Yield

Table 3. Simulated Impacts of Interventions on Vegetable Consumption, Prices Received and Profits for Supply Chain Actors

Simulated Outcome	Dynamic Equilibrium	Increase Awareness	Decrease Farm Perishability	Increase Farm Yields
Average Daily Per Capita Vegetable Consumption, grams/day	131.2	134.0	130.9	153.0
Ending Daily Per Capita Vegetable Consumption, grams/day	131.2	136.2	130.8	173.8
Average Total Quantity Consumption, million kg/week	3.02	3.08	3.01	3.52
Ending Total Quantity Consumption, million kg/week	3.02	3.13	3.01	4.00
Average Price Received, KSh/kg				
Farm	22.0	22.7	22.5	17.6
Intermediary	45.0	46.5	45.2	45.6
Vendor (Paid by Consumer)	53.7	55.4	53.7	56.0
Average Total Profits, million KSh/Week				
Farm	31.7	34.6	29.0	16.3
Intermediary	23.5	26.7	22.2	48.3
Vendor	7.5	8.7	7.1	15.9

3.2 Results of Stochastic Intervention Scenarios

The values of many parameters describing the response of supply chain participants are not well known, and the participants in the April workshop expressed different opinions about many of them. Given the uncertainty about these values, it is important to evaluate how alternative assumptions about them affect the impacts of the priority interventions. To do this, we specified likely ranges of values from many of the uncertain parameters and used these ranges to simulate N=200 random combinations of uncertain parameters for each of the interventions and their combination. Lacking good information about the nature of the distribution for these parameter values, for all of them we assumed a uniform probability distribution for specified maximum and minimum values, using the 'multivariate' selection approach provided by the Vensim™. For the three interventions, we assumed the same magnitude of impact as in the deterministic scenarios (e.g., a 10% increase in awareness) but simulated a range of costs changes and response parameters associated with achievement of that impact. These analyses provide a probability distribution of values for vegetable consumption, which is appropriate given the uncertain nature of value-chain behavioral responses.

The stochastic analyses indicate that the range of impact of the three interventions on simulated vegetable consumption can vary based on assumptions about value-chain responses and the effect on value-chain costs (Table 4). The range of values at the end of 2024, which tend to be the highest values of consumption for reasons discussed previously, varies by only 6 grams/person/day for scenario of reduced perishability but is larger of the scenarios modifying consumer awareness (nearly 40 grams/person/day) and increasing farm yields (84 grams/person/day) (Table 4 and Figures 4 to 6). The range of consumption outcomes at the end of 2024 is greater than 10% of current consumption for the scenarios except for the reduced perishability scenario, which suggests the importance of understanding which uncertain parameters have the largest impact on the outcomes.

The impact of alternative parameter values was assessed using a linear regression of the end-of-2024 consumption level on the parameter values used in the 200 simulations for the stochastic analysis[5]. The sign and magnitude of these regression coefficients can be used with information about the low and high values of the parameters used in the 200 simulations to assess the impacts on consumption of changes in specific parameters. As an example, for the scenario increasing awareness of nutritional benefits, a 10% increase in awareness is assumed, but the sensitivity of consumption to awareness is uncertain, with a range of values from 0.2 to 1.0. Given the regression coefficient for sensitivity of consumption to awareness the impact of a change from 0.2 to 1.0 in the value of the sensitivity indicates that the impact of changing from the low and high values of sensitivity is about 16 grams/person/day. A value of 16 g/p/d is about 40% of the observed range of values, suggesting that uncertainty in this parameter accounts for a substantive amount of the 38 grams/person/day uncertainty observed for the

[5] A linear regression may not fully capture nonlinear effects of changes in parameter values but provides an initial assessment adequate for present purposes.

range for this intervention assuming other factors held constant. For the perishability scenario, the only important parameter was the assumed cost, which accounted for two-thirds of the variation in 2024 outcomes. For farm yields, assumptions about the cost changes required for yield (a 5% decrease to a 10% increase) accounted for the majority of the variation observed in consumption outcomes.

Overall, these stochastic analyses suggest that substantive increases in F&V consumption are unlikely with reduced perishability under any assumed values for uncertain model parameters. However, there is a potential for substantively larger increases in F&V consumption than is predicted by the mean values of parameters for interventions to increase consumer awareness and farm yields. Moreover, there is overlap in the distributions of F&V consumption outcomes under uncertain parameter values for these latter two scenarios. Further work to define more narrowly the values of uncertain parameters would be beneficial to the identification of more effective interventions.

Table 4. Range of Simulated Impacts of Interventions on 2024 Vegetable Consumption, N=200 Random Sets of Parameter Values

Simulated Outcome	**Increase Awareness**	**Decrease Farm Perishability**	**Increase Farm Yields**
Average Daily Per Capita Vegetable Consumption, grams/day			
Minimum value	131.6	125.1	121.6
Median value	136.9	130.5	171.3
90th percentile value	149.8	131.2	194.4
Maximum value	169.6	131.2	205.6
Range of values (Maximum – Minimum)	38.0	6.1	84.0

NOTE: Consumption in Dynamic Equilibrium is 131.2 g/person/day.
[a] The combined scenario includes all interventions other than Decrease Farm Perishability.

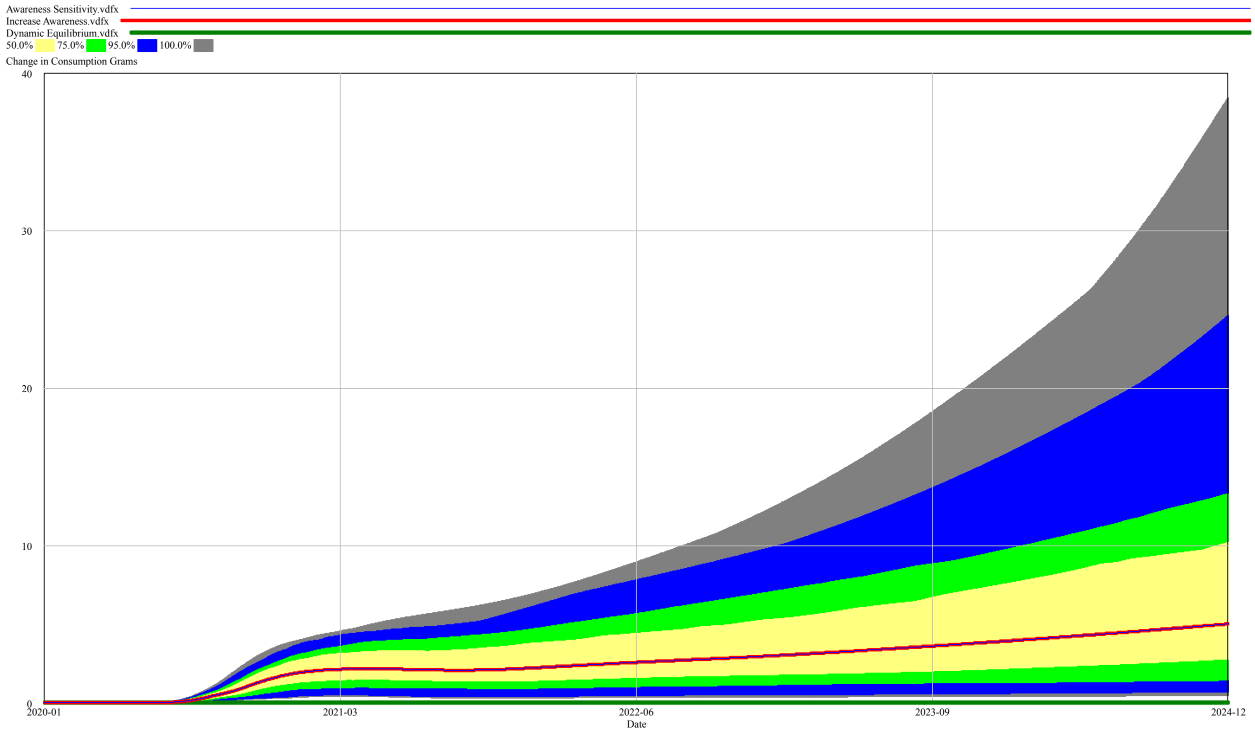

Figure 4. Simulated Range of Changes in Daily Per Capita Vegetable Consumption with 10% Increase in Awareness of Nutritional Benefits, N=200 Random Sets of Parameter Values

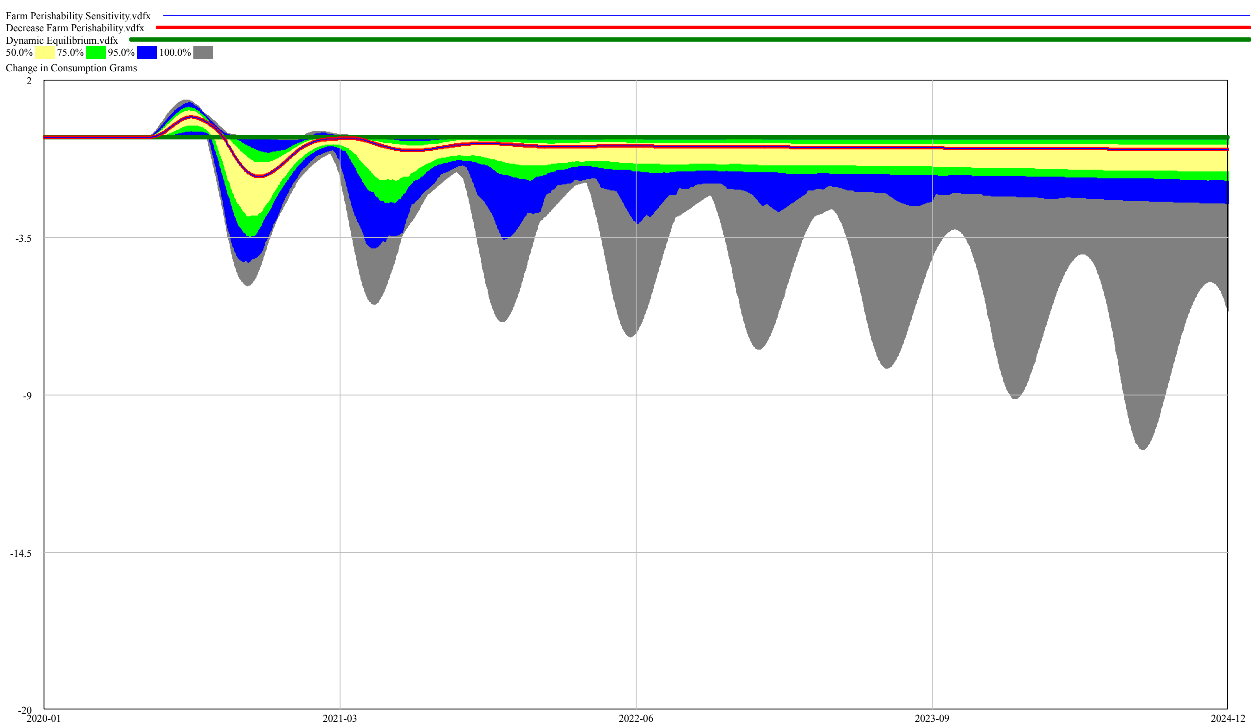

Figure 5. Simulated Range of Changes in Daily Per Capita Vegetable Consumption with a 33% Reduction in Farm Perishability, N=200 Random Sets of Parameter Values

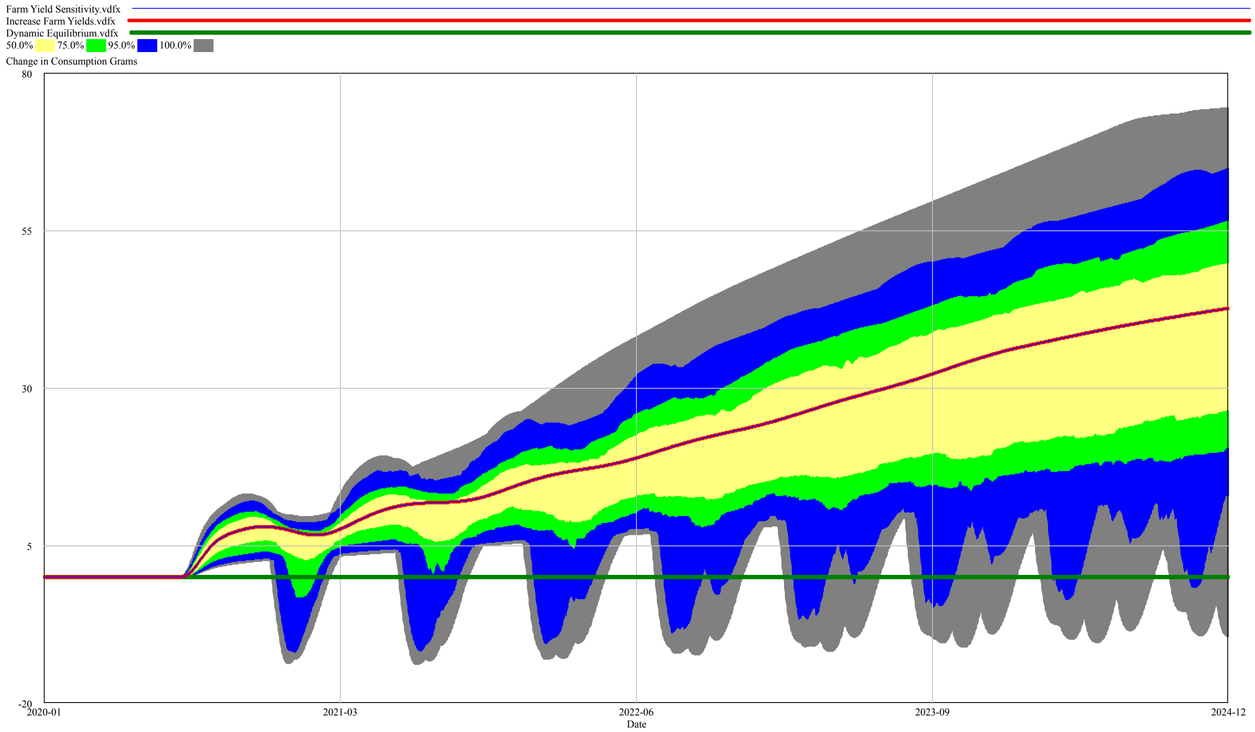

Figure 6. Simulated Range of Changes in Daily Per Capita Vegetable Consumption with 50% Farm Yield Increase, N=200 Random Sets of Parameter Values

4 Conclusions and Implications

4.1 Conclusions

The principal conclusion of this process is that interventions to increase F&V consumption in urban Kenya may provide benefits but also face challenges. Reducing perishability is unlikely to result in substantive increases in F&V consumption even accounting for uncertainty in parameter values. Increasing consumer awareness has modest impacts on F&V consumption at the mean assumed values of many parameters but would have more impact if the responsiveness of consumers to awareness is larger than the mean value assumed or if demand for F&V is less elastic (in the economics meaning of that term). Increasing farm yields appears to have the largest potential to increase F&V consumption, but also implies large reductions in farmer profits—an undesirable outcome that could undermine attempts to implement yield-increasing programs.

4.2 Implications and Future Actions

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 this information was evaluated with the simulation model, the relatively large ranges of outcomes indicated by the stochastic analyses suggests that allocating resources to improved knowledge would be valuable. Three main areas merit further knowledge development. Additional information on the cost structures and prices through the value chain (e.g., Chemonics, 2013) and their changes over time and in response to interventions would allow improved representation of core business performance metrics and likely behaviors. Information on the responsiveness of consumers to changes in factors such as quality, convenience, hygiene is very limited; extant studies often include ranking of 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.

The suggested next steps are to use the results of this modeling study to undertake a series of small exploratory studies to improve knowledge of value-chain relationships, consumer consumption behavior and the potential for interventions to modify key value-chain components and affect consumption behavior. This information could be used to refine the analyses reported herein—to narrow the range of possible outcomes currently due to data uncertainty.

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