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Quantification and benefits of reducing post-harvest losses: Evidence for vegetables in Senegal

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Abstract

This study examines on-farm post-harvest losses (PHL) for three vegetable crops (onion, tomato, and pimento) in Senegal and the potential economic benefits associated with reducing PHL for these three vegetables. Household survey data was used to quantify the on-farm PHL for these vegetables at different stages between the crop's harvest and the sale or consumption. A multi-market model was used to simulate the effect of eliminating vegetable PHL on the total value of vegetable supply and international trade of vegetables at the national level. Results suggest that on average 30% of vegetable production is lost on-farm and is therefore unavailable for sale or consumption. Eliminating these losses could increase the total value of vegetable supply by 45% (US $72 million) per year and reduce vegetable imports by 22% (127,000 tons) per year. Moreover, our results indicate that both private costs to farmers and public costs to the government related to such PHL reductions would need due consideration when prioritizing between investments in the agricultural sector and beyond.

Keywords: Post-Harvest Losses, Vegetables, Multimarket partial equilibrium model, Senegal

JEL codes: O13, Q18, D58, O55

1. Introduction

The expected rapid increase of the global population will go hand in hand with a rise in food demand (Gouel & Guimbard, 2018; Davis et al., 2016).Increasing the availability of agricultural products in sufficient quantity and quality to a growing feed population is consequently one of the major challenges for food security, especially in developing countries.[1] According to several studies, increases in agricultural productivity will not be sufficient; it will also be necessary to reduce post-harvest losses in order to increase the quantity of food available (Hengsdijk & de Boer, 2017; Affognon et al., 2015). The FAO (2011) estimated that, each year, about one third of the world's food production for human consumption is lost or wasted before it is consumed. An assessment of the global economic value of these losses reveals that it amounts to 1.3 billion tons per year or 30% of total agricultural production (Foresight, 2011; Gustavsson et al., 2011; Lundqvist et al., 2008). In sub-Saharan Africa (SSA), the region of the globe where the undernourished percentage of the population is highest, the volume and value of these post-harvest losses estimates are alarming, highlighting the urgency to better understand and reduce post-harvest food losses.[2] Zorya et al. (2011) estimated SSA post-harvest losses (PHL) at US$ 4 billion a year, which would be enough to feed 48 million people for a year while the FAO (2011) estimated it as approximately 37% of all food production.

Food losses can be measured in quantitative and qualitative terms (Shee et al., 2019). Quantitative losses occur when the actual physical amount of food reduces over time and space, while qualitative losses occur through the loss of nutrients, visual aesthetic appeal or breakage or contamination of food, amongst other factors (Sheahan & Barrett, 2017). Large amounts of foods are physically lost as agricultural commodities move along their value chains (Shee et al., 2019). The economic impact of PHL has motivated the integration of an objective on food loss reduction by 2030 as part of the Sustainable Development Goals under SDG 12.3 (Corrado et al., 2019). The specific target of SDG 12.3 is to "By 2030, halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses" (Lipinski et al. 2017). Although these high-level SDG targets provide an aspiration and broad encouragement at the global level, country-specific analysis are critical to provide quantitative evidence towards meeting the targets. It is therefore necessary to question the extent of PHL at the national level and the benefits of reducing PHL for specific crops or groups of crops.

A major challenge to post-harvest loss reduction from a policy perspective is the lack of empirical information on how changes in on-farm PHL flow on to affect broader issues at the

[1] Our study followed the FAO (2008) definition of food security, which is broad, but still useful (Pinstrup-Andersen, 2009): food security occurs when people have physical, economic and social access to sufficient and varied food for a healthy diet. This definition encompasses four dimensions: food availability, access, utilization, and stability.

[2] Africa remains the continent with the highest prevalence of undernourishment with a rate of 21% of the population (over 256 million people) (FAO, 2019).

national scale such as the value of supply available for sales or consumption and changes in international trade. Our paper addresses two research questions: (1) what is the extent of vegetable PHL in Senegal? and (2) what is the effect of an elimination in these vegetable PHL on the economic value of total supply available to farmers and international trade? Uncertain estimates of PHL, coupled with an imprecise understanding of their impact on economic and international trade indicators, could lead to suboptimal policy choices (Affognon et al., 2015). The reduction of PHL, particularly for vegetable farmers, may lead to an increase in marketable surpluses and therefore farmer income, but also to lower consumer prices under the condition that there is neither a change in demand nor extra supply available to be sold to consumers. In fact, if PHL are reduced then more of the production may become available to farmers to 1) consume on-farm or 2) sell on the market (Beune, 2018).

We use household survey data to examine the extent of PHL for Senegal's main vegetable products, onion, tomato and pimento, and then use a multi-market model to simulate the effect of an elimination in PHL on the economic value of total supply available for sales or consumption by farmers and international trade.[3] The importance of vegetables in achieving food and nutrition security objectives is well established (Van Rensburg et al., 2007; Van Wyk & Gericke, 2000). If the reference diet from the EAT-Lancet Commission (Willett et al., 2019) was followed there would be a substantial increase in the demand for vegetables globally, presenting increased economic opportunities for vegetable farmers. However, as they are perishable crops, vegetables are especially vulnerable to PHL (Affognon et al., 2015), and reducing PHL would help increase the supply available to consume or sell, especially for poorer rural households.

The paper is structured as follows. We first describe the state of the literature on PHL with a focus on sub-Saharan Africa. The context of vegetable production in Senegal is presented in the next section, notably the developments and political decisions relevant to onion, tomatoes and pimento value chains. The following section presents the research methodology including descriptions of the multimarket partial equilibrium model and PAPA survey data used. Finally, we report and discuss the results of our descriptive statistics and simulation, before concluding.

[3] PHL occur after crop harvest so they do not have a direct effect on production (i.e., kg vegetable produced per farm), but PHL affect the quantity of crop available for consumption or sale.

2. PHL in sub-Saharan Africa

Reducing PHL is a key pathway to food and nutrition security in sub-Saharan Africa (Affoghon at al., 2015). A review of recent literature shows a renewed interest of PHL reduction in SSA specially on the motivations of public policies, the estimation of its magnitude and the impact of technologies on PHL reductions. Lipinski et al. (2017) identify three benefits related to reducing PHL: (i) an increase in supply of the crop that may ultimately increase food security, mainly through increased food availability; (ii) an increase in household incomes associated with extra sales of crops that could reduce poverty; and (iii) a reduced pressure on climate, water, and land resources.

Sheahan and Barrett (2017) enumerated four multifaceted objectives underpinning the SDG 12.3 to understand the reasons for the renewed interest in PHL reduction in SSA. The first objective is to improve food security by increasing food supply, which, under normal circumstances, should also translate into a reduction in prices for consumers, thereby improving overall food access. The second objective is to improve food safety, as sometimes spoilage or contamination is not perceptible to the human senses and goes undetected, leading to adverse health effects when food is consumed. The third objective is to reduce unnecessary resource use associated with PHL. Finally, the fourth objective is to increase profits for food value chain actors as profit is a common objective of commercial entities and reducing waste will lower costs.

The urgency to reduce PHL in SSA depends largely on the magnitude of such losses relative to optimal PHL levels. In a meta-analysis focusing on SSA, Affognon et al. (2015) reveal a growing interest in PHL research and development, or at least an improvement in the communication of PHL research results in the 2010s. They also note that most studies were based on household surveys, field trials, and laboratory experiments and targeted storage, followed by marketing and harvesting, whereas the attention to other levels of value chains has been minimal. PHL can occur anywhere between farmers' fields and consumers' plates (Beune, 2018): drying, winnowing, cleaning, on-farm storage, handling, milling, processing, transport, larger-scale mixed storage, retailing, and consumers' home storage, meal preparation, and consumption (Sheahan & Barrett, 2018). The magnitude of farm-level post-harvest quantitative losses reported in the literature vary widely depending on the local context, the crop studied, and PHL technologies available. Affoghon et al. (2015) revealed that the largest magnitudes of losses across SSA occur in fruits, vegetables, root crops, and tuber crops. Reasons for these magnitudes are the perishable nature of these commodities and the poor post-production infrastructure for handling perishable commodities across SSA. Estimating the economic value losses for fruits and vegetables in SSA, Kitinoja (2010) found that along the entire value chain 16–40% of production are lost. Besides loss of revenue, a main manifestation of quality deterioration is nutrient degradation and bio-contamination, meaning loss of food value and occurrence of foodborne health hazards. The FAO (2011)

Global Food Loss and Food Waste study estimates losses across SSA of about 20% of all cereals, 44% of roots and tubers, and 52% of fruits and vegetables between harvest and consumption.

Omotajo (2018) examined the relationship between agribusiness investments and PHL and how these investments had impacted food security in Rwanda. He showed that investments targeted at closing storage and drying gaps is pivotal to changing the practices that allow for PHL. Quantifying total food waste generation in South Africa, including both pre-consumer food losses, as well as post-consumer food waste, Oelofse (2012) estimated the annual magnitude of food waste generation in the order of 9.04 million tons or 177 kg/capita with a consumption waste of 7 kg/capita.

Other studies have examined the impact of technology on PHL reduction. Chegere (2017) tested the effect of two types of PHL reduction interventions in Tanzania including the provision of hermetic bags and its combination with training for improved post-harvest management of crops. He found an Internal Rate of Return (IRR) of 14% for farmers who received a hermetic bag only, while those who additionally received a post-harvest good practice training had an IRR of 35%. Fischler et al. (2011) examined the economic impacts of using metal silos for maize storage in Honduras, Guatemala, Nicaragua and El Salvador and found a 23% increase in income among users and a benefit-cost ratio of 2.6. Wanjiku (2018) determined how the storage management strategies influence post-harvest cereal loss in Kenya. He found a significant reduction of PHL when improved storage facilities are used. Therefore, considering the strategies for reducing food losses and waste among the SDGs is of great interest given the urgency of increasing agricultural production to feed a growing population.

3. Vegetables in Senegal: a contextual overview

Agriculture has always held a prominent place in Senegal's economic and social development policies. Even today, it represents a key sector for the economic and social development of the country, given the high percentage of the population that directly depends on it as well as its strategic dimension in terms of food security, poverty reduction, and contribution to the regulation of macroeconomic and social balances (PSE, 2014): Family farms in Senegal make up more than 60% of the working age population and provide more than 80% of the national agricultural production. Improvements in the agriculture sector can reduce poverty directly by increasing farmers' incomes, and indirectly through employment creation and lower food prices.[4] Despite agriculture contributing only 15% to the GDP, the National Accounts for 2015 indicate that the primary sector continues to be the main employer in the country, absorbing approximately 46.3 percent of total employment, of which around 26.2 percent is in agriculture, while the rest is mainly in livestock, forestry, and fisheries (World Bank, 2018).

Most cultivation in Senegal is rainfed apart from that in the Senegal River Valley, where crops are also irrigated, and the area of Niayes, where almost all crops are irrigated. Vegetables and fruits mostly grown in the areas of Niayes and the Senegal River Valley, both of which play an important role for the economy. Vegetable production has developed considerably over the past twenty years in Senegal with total production increasing from 281,464 tons in 2005 to 886,130 tons in 2015. This increase in production has had positive effects on the supply of fresh vegetables to the domestic market, the creation of incomes for farmers, and international trade (ANSD, 2019). As part of this study, we will focus on onion, tomato and pimento which account for 52.46% of total vegetable production.[5]

The supply of vegetables, although having increased over time, is insufficient to meet domestic demand during winter, with shortages in the main vegetable markets leading to imports. Indeed, most vegetable production takes place during the dry season. It begins in October-November and ends with the definitive start of the rains (July). However, the marketing of vegetable products poses several problems because of their seasonality and perishability, combined with the absence of storage technologies which would reduce PHL and guarantee higher prices and therefore an increase in producers' incomes. In this section of our study, we present the specific context of the three products of our study, onion, tomato and pimento, and show how PHL impact the quantity of produce available for farmers to consume or sell on the market.

[4] Our study follows the International Labour Organization definition of active population: >= 15 years old and < 65 years old.
[5] Author's calculation based on FAOSTAT.

3.1. Onion

Onions are used daily in every Senegalese kitchen and have consequently always been at the center of public policies for vegetables. Until 1995, the import authorizations were made according to the quantity of local onions marketed. Indeed, the government provided onion import quotas based on the amount of local onions collected and marketed by importers (Pelletier, 1997). The resulting increase in imports exposed local supply to competition from imported onions, with a saturation of the market that led to a collapse of prices and the local onion flow, especially during periods of peak harvest. Thus, since 2004, the Senegalese government has attempted to create incentives for the local production of onions through protectionist measures aimed at restricting imports and suspending them during periods of peak harvest, applied under the supervision of the market regulation agency (ARM) and in consultation with producer and trader organizations. The first attempt was a seven-month ban on onion imports (from February to August). Conscious of the insufficient quality of local onion stocks and the absence of storage means which force producers to sell as quickly as possible, the government of Senegal aimed to reach its goal of self-sufficiency in onion supply by 2017 through the development of new irrigation schemes, input subsidies, technical support, the renewal of seed capital and the creation of storage systems to meet the challenge of conservation and PHL.

Onion production has evolved in line with public policies, increasing from 245,000 tons in 2014 to 368,000 tons in 2015 and 400,000 tons in 2017 (Figure 1). Despite this increase in production, which exceeds the estimated annual onion demand of 350,000 tons (PRACAS, 2014), Senegal still imports onions for 3 to 4 months each year, partially because PHL remaining high. Indeed, in 2016, imports were 151,205 tons, a 15.5% increase compared to 2015 (ANSD, 2019). With a single growing season, the seasonality of supply and the inability to spread marketing throughout the year are major constraints that the onion industry is facing. Indeed, onion production remains concentrated between February, March and April with the marketing campaign being spread from March to October. The use of imports is linked to the deficit of storage infrastructure and conservation (such as dry shelters and cold rooms) (ANSD, 2019).

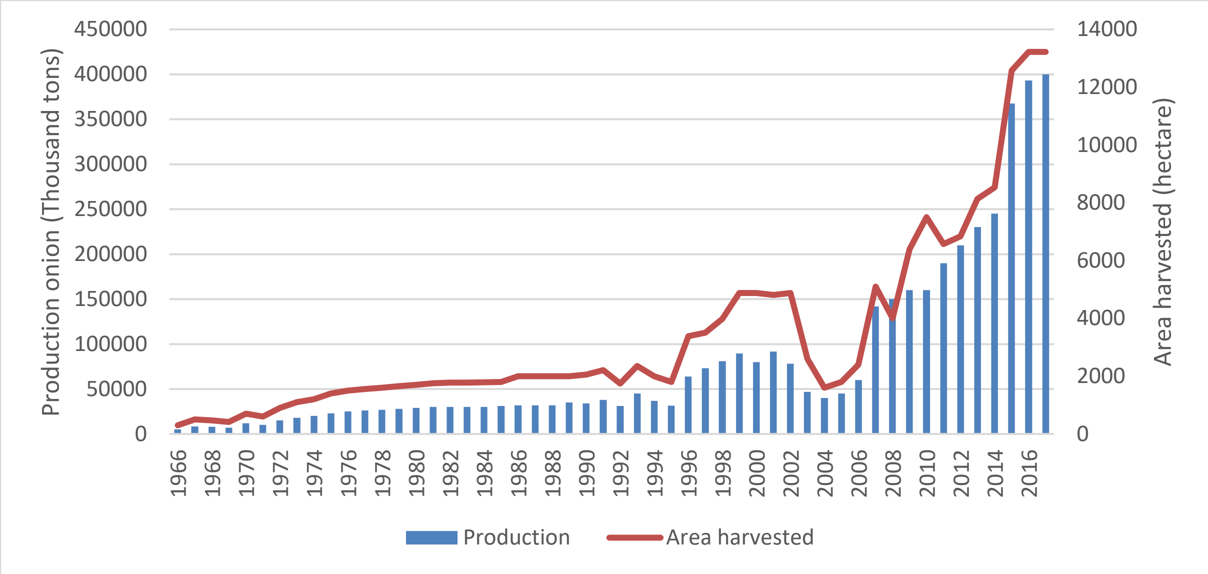

Figure 1: Production and area harvested of onion

Source: FAOSTAT (2019).

3.2. Tomato

Most of the Senegalese tomato production comes from the Senegal River Valley, where farmers specialize in producing industrial tomatoes, and from the Niayes area, where cherry tomatoes dominate. The industrial tomato sector is one of the most successful forms of contract farming in Senegal. The performance of this sector, however, is linked to production conditions with irrigation development and processing units that limit the uncertainties of transactions. In Niayes, the production of fresh tomatoes as well as the sorting gaps of cherry tomatoes produced by the farming companies are feeding the urban markets. Prices considered low by producers have always been at the center of developments in the tomato sector. In order to avoid crop losses, producers are sometimes obliged to sell at a low price to intermediate traders because of the lack of treatment centers, storage and adapted technologies.

With the aim of achieving self-sufficiency in cherry tomatoes at national scale, the gap that remains to be filled is substantial, since the annual domestic demand for cherry tomatoes is estimated at 120,000 tons while the national production has only reached an annual average of 81,000 tons in recent years (PSE, 2014). In the industrial sector, competition between manufacturers (SOCAS, AGROLINE and TAKAMOUL) which share the market for tomato concentrate, although beneficial for consumers, is damaging the competitiveness of producers, such that they are discouraged from producing a high yield. This explains the fall in production during the last seasons since, on a target of 78,000 tons, only 37,000 tons of tomato were removed by industrial companies and the producer price per kilogram of tomato remained unchanged (Diouf, 2016).

Tomato production experienced its first major developments in the early 1980s with the establishment of a second processing industry in Dagana in the 1980s by the *Societe Nationale de Tomate Industrielle* (SNTI), in addition to the first processing industry established by SOCAS, and the improvement of tomato producers' access to credit with the implementation of the national agricultural bank *Caisse Nationale de Crédit Agricole du Senegal* (CNCAS). Subsequently, the devaluation of the Senegalese currency CFA-Franc in the early 1990s led to an increase in input costs and a low revaluation of the price paid to the producers which increased from 30 CFA-Franc/kg to 32.5 CFA-Franc/kg in 1994 (Fall et al., 2010). This disagreement between manufacturers and producers over the price of tomatoes has led to a drop in production volumes collected by industry and an increase in the importation of triple tomato concentrate. It is clear that the arrival of new manufacturers in the sector has gradually changed the structure of industrial demand, marking the end of the monopoly of processing, but local production is still insufficient to meet the demand of manufacturers who are obliged to import triple concentrate to supplement the raw material (Figure 2).

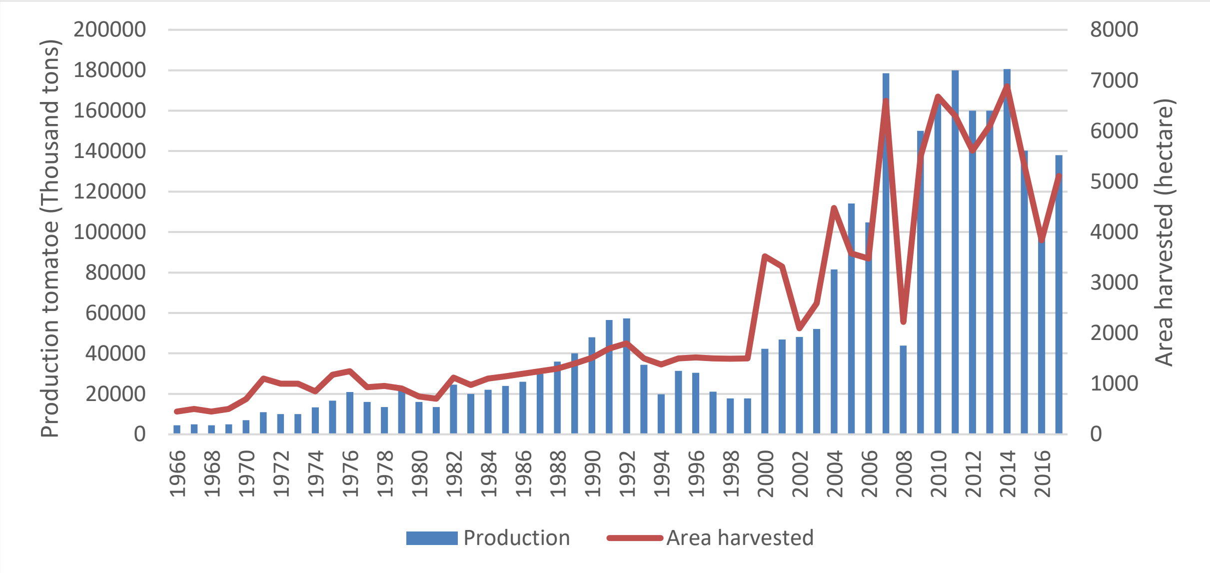

Figure 2: Production and area harvested of tomato

Source: FAOSTAT (2019).

3.3. Pimento

In Senegal, pimento has not yet been the subject of a major specific policy program. It is used as a condiment in most Senegalese dishes to enhance the taste of the food. Pimento contains more vitamin A than any other fruit or vegetable and is an important source of vitamin C, magnesium and iron (Willett et al., 2019). In Senegal, there are several varieties of pimento including "Goana", "Saddam" and "Tyson". The per capita consumption of pimento is estimated at 0.4 kg/year (ANSD, 2016), which is low compared to an annual consumption of 15.7 kg/capita in Mexico or 2 kg/capita in Cameroon.

Like the other tropical countries, the quantity and quality of pimento production in Senegal is negatively affected by the high parasite pressure associated with hot and humid weather conditions. Hence, pimento yields are vulnerable to weather extremes that create challenges for ensuring stable production throughout the year (Figure 3). The evolution of production is strongly correlated with the area planted, with tomato production and area harvested reaching a peak in 2006 as a result of the launch of a government initiative called the Great Agricultural Offensive for Food (GOANA) which allowed the introduction of new pimento varieties.

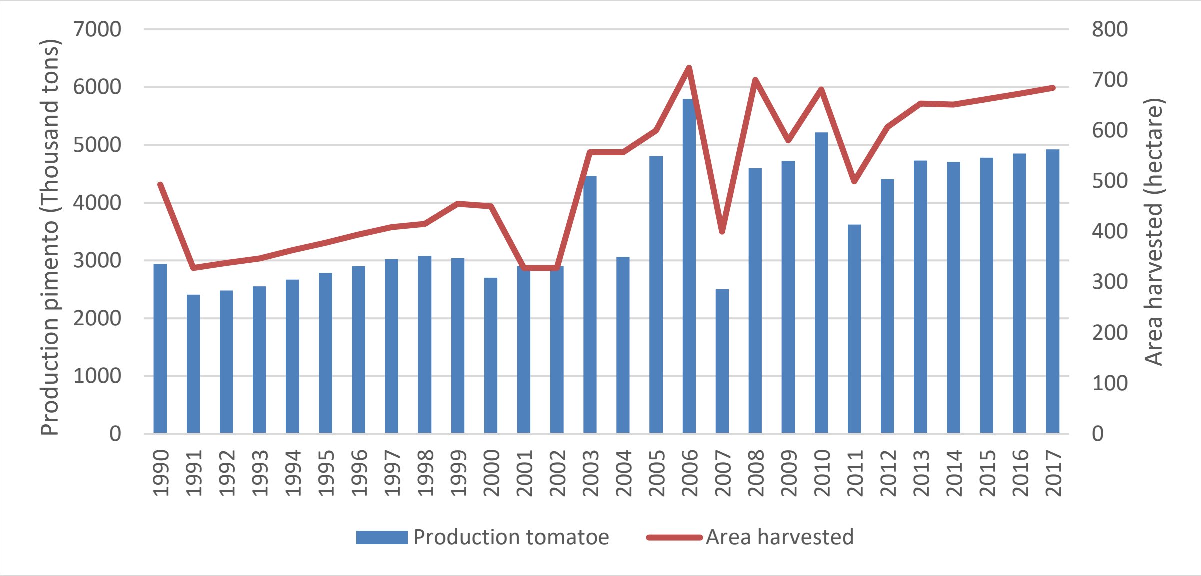

Figure 3: Production and area harvested of pimento

Source: FAOSTAT (2019)

4. Methodology and data

4.1. IMPACT-SIMM

In this part we will first describe the IMPACT-SIMM multimarket partial equilibrium model before presenting the design of the baseline and PHL scenarios.

4.1.1. Model description

To simulate the effect of changes in PHLs in Senegal at the national level, we used the International Model for Policy Analysis of Agricultural Commodities and Trade – the Standard IFPRI Multimarket Model (IMPACT-SIMM). IMPACT-SIMM is a country-specific multimarket partial equilibrium model for the agricultural sector that enables the exploration of different agriculture and food systems scenarios at the country scale (Rosegrant et al., 2015; Ye et al., 2014). It is a partial equilibrium model because it only simulated agricultural commodities and not the manufacturing and tertiary sectors. It is a structural model as it simulates the operation of commodity markets and the behavior of economic agents, including producers and consumers. The notation and structure of IMPACT-SIMM closely follow the full IFPRI IMPACT model (IMPACT3)[6]. The main difference between IMPACT3 and IMPACT-SIMM is that IMPACT3 is a global model covering 159 countries, but IMPACT-SIMM is a single-country model. The data to populate model parameters used for the IMPACT-SIMM simulation scenarios for Senegal were extracted from the full IMPACT dataset, with PHL data coming from the PAPA survey to inform the simulation scenarios.

IMPACT-SIMM simulates the operation of national commodity markets by equating total demand with total supply for specific commodities. For each commodity, domestic production (area cultivated × yield) plus imports and change in stocks, together equaling domestic demand (i.e., consumption), plus exports. Data on commodity yields and area cultivated are taken from FAOSTAT, as stored in the IMPACT3 database (Robinson et al., 2015). Yields and areas cultivated in different simulations can change if the model is simulated over different years, with yields changing based on the price of inputs, intrinsic productivity growth rates, and the price of the commodity. Areas change based on the price of land and the marginal revenue product of land. Domestic demand for a commodity is the sum of household food demand, agricultural intermediate demand (feed and processed goods), and intermediate demand from other sectors (such as biofuels). Food demand is a function of the commodity price, the price of other commodities, per capita income, total population, and the price and income elasticities of demand. IMPACT3 solves for a world price for each commodity where net trade over the globe is zero (i.e., exports equal imports, summed over all 159 countries),

[6] IMPACT3 is a network of linked economic, water, and crop models that permits the integrated analysis of the impact of changing environmental, biophysical, and socioeconomic trends on agriculture and food (Robinson et al., 2015).

with national production and demand linked to the world markets through trade. Because we used IMPACT-SIMM for the a single-country case of Senegal, the world price was fixed in IMPACT-SIMM in a specific year (but could fluctuate over time). Export and import prices are country-specific and are pegged off the world price with adjustments for country-specific tariffs, producer support estimates, and marketing margins.

IMPACT-SIMM uses a mixed complementarity problem formulation for trade, with separate import and export variables (Robinson et al., 2015). A commodity may not be traded in a specific country in a specific year depending on the gap between the export and import prices in the country. There are price inequalities for consumer prices of a commodity relative to import and export prices. There must be a price wedge, so that the domestic price of exports is less than the domestic price of imports. If domestic consumer prices are between the export and import price then there is no trade, and if the domestic consumer price equals the import price then the commodity is imported by the country, likewise if the domestic consumer price equals the export price then the commodity is exported by the country. Within the model the essential condition for trade is that net trade (exports minus imports) equals domestic production minus total domestic demand minus change in stocks.

4.1.2. The baseline scenario

We sequentially ran IMPACT-SIMM on a yearly time step for the years 2005 to 2030 using model parameters imported from the IMPACT3 dataset. We report results for the year 2016. The baseline scenario aims to reflect the agricultural market situation in Senegal in 2016. It is a "business-as-usual" scenario that is used to provide a comparison point for a PHL elimination scenario described in Section 4.1.3. Because PHL are present in Senegal in the vegetable sector, these are included in the baseline scenario. Vegetables in IMPACT-SIMM are treated as an aggregate activity and the aggregate vegetable activity is made up of five vegetable commodity groups: tomatoes, onions, pepper, pimento, and other vegetables. In Senegal the vegetables of importance for our study included onion, tomato, and pimento.

To incorporate PHL into IMPACT-SIMM to reflect the PHL observed among farmers, we made an adjustment between the quantity of vegetables produced on-farm and the quantity of vegetables available for the farmer to consume or sell, i.e., not all on-farm production is available for the farmer to consume or sell because some PHL may occur. We added one equation into IMPACT-SIMM to reflect that the PHL are specific to vegetables in Senegal: total supply available for sales or consumption by farmers = (1 − PHLPARA) × (yield × area). We reduced the quantity of vegetables available by a PHLPARA parameter based on the PAPA data. The parameter PHLPARA is a portion in the domain 0 to 1, meaning that for example a value of 0.2 implies that 20% of production is lost post-harvest and not available for the farmer to consume or sell. To obtain the PHLPARA parameter, we used the PAPA survey data on PHL for individual farmers and calculated a weighted average of the individual crops' PHL for onion, tomato, and pimento with the weight based on the proportional contribution of the individual crop to the total value of production for the three crops at the national scale. The PHLPARA parameter was obtained from the PAPA survey, and we used a single value from the PAPA farm surveys in IMPACT-SIMM.

4.1.3. PHL scenario

We used IMPACT-SIMM to simulate a "what-if" scenario related to eliminating all PHL for vegetables produced domestically in Senegal. In the PHL scenario the PHLPARA parameter became zero and all production became available for the farmers to sell or consume. Our intention was to focus on investigating the benefits of reducing PHL; however, achieving this reduction will entail costs, some of which we canvass in our discussion section.

4.2. PAPA survey

We used data from the Agricultural Policy Support Project (in French: Projet d'appui aux politiques agricoles—PAPA) household surveys organized in 2017 to characterize vegetable PHL in Senegal. The survey was conducted by the Senegalese Agricultural Research Institute (ISRA). The horticulture sample covers the two main areas of horticulture production of Senegal: 1) the Niayes, which is a geographical area in northwestern Senegal and 2) the Senegal River Valley, which is in the North of Senegal. The sample was obtained using probabilistic two-stage sampling, stratified at the first stage.

The Niayes area is located on the west coast of Senegal between Saint-Louis and Dakar and extends over a length of 180 km and a width ranging from 5 to 30 km. Although with moderate annual rainfall averaging not less than 200 mm in the north and 400 mm in the south, the Niayes previously enjoyed favorable conditions for irrigation by the presence of shallow groundwater. These hydrological characteristics explain the local prominence of vegetable and arboriculture production mainly intended for the domestic market. The horticultural producers' census undertaken by the Department of Horticulture in 2015 was used as a sampling frame with 10,163 producers. The primary units or units of the first stage are constituted by the horticultural production sites/villages, and the secondary units or second stage units are composed of the horticultural households. To obtain comparable results at the finest possible level, the sampling frame was divided into 25 strata corresponding to the local communities (rural communes) that cover the Niayes area.

The aim was to provide comparable results at the level of different strata. The horticultural production sites (primary units) are drawn with replacement, with probabilities proportional to their size expressed in the number of horticultural farmers. At the level of each primary unit (horticultural site) of the first stage, a fixed number of ten horticultural farmers is selected equally and without replacement, depending on the number of horticultural farms on the site. The overall sample of this study is made up of 1,305 households in the different zones. Table 1 summarizes the sample.

Table 1: Horticulture survey sample size distribution

Zone	Department	Number of producers
Niayes	Rufisque	96
	St-Louis	145
	Thiès	159
	Tivaouane	212
	Kébémer	247
	Louga	91
	Total Niayes	950
Senegal River Valley	Dagana	173
	Podor	182
	Total Senegal River Valley	355
Total sample		1305

Source: Projet d'Appui aux Politiques Agricoles (PAPA, 2017).

5. Results and discussion

We present and discuss two types of results in this section. First, PHL will be evaluated with a descriptive analysis for onion, tomato, and pimento. Second, we present the simulation results from the multi-market model of an elimination in PHL for vegetables on the economic value of total supply available for sales or consumption by farmers and international trade.

5.1. Descriptive analysis of PAPA survey PHL data

PHL can be assessed at different stages of agricultural value chains. In this study, losses are measured at the producer level and include all on-farm post-harvest activities ranging from drying, storage and transportation to marketing. We considered the main crops grown among surveyed farmers, which where onions, tomatoes, and pimento. Unlike Kaminski & Christiaensen (2014) who studied maize in Malawi, Uganda, and Tanzania, for which losses concerned less than one-fifth of the households surveyed, our descriptive analyses show that PHL in Senegal occur for 48% of vegetable farmers. However, Wanjiku (2018) notes that for cereal producers of Kenya, 62% of the respondents experienced PHL.

Table 2 reports the PHL for the main vegetables produced in Senegal. For the reported crops, vegetable growers lost 31.2% of the production between on-farm harvesting and sales or on-farm consumption. These results are similar to other PHL studies on vegetables in SSA. Indeed, due to their perishability, fruits and vegetables are known for their losses, which are estimated between 30% to 50% of total production in SSA by FAO (2011) and 43.5 ± 16.6% by Affognon et al. (2015). Kughur et al. (2015) note that fruit and vegetable PHL in Nigeria account for between 35% and 45% of annual production. They further note that these losses are due to mismanagement after harvest, as well as the lack of appropriate processing and marketing facilities. Limited knowledge and skills regarding post-harvest handling techniques mean that most farmers do not follow the recommended good post-harvest practices (Niang, 2019).

Of the three vegetables we studied, onions suffer most from on-farm PHL with 32.1% of production lost. Our result is thus slightly higher than those found by Sharma (2016), who estimates PHL for onion producers in a district of India at 28.93%. Niang (2019) noticed a lack of storage technology and infrastructure for onions in the marketplace. Onions are often transported in over packed storage bags and then left out in the sun for several days, waiting for buyers. Regarding tomatoes, our analysis shows a PHL rate of around 28.6% in Senegal, while a collection of 8 studies on PHL of tomatoes highlight PHL rates between 10.7% and 33.7% (Affognon et al., 2015). For pimentos, we calculated the PHL at 29.8% of total production.

Table 2: Post-harvest losses by crop in Senegal for the agricultural season 2015/16

	Average	Standard deviation	*CV*	Minimum	Maximum	*N*
Crop						
Onion	32.1	15.9	0.50	0.0	85.7	507
Tomato	28.6	13.8	0.48	0.0	72.8	149
Pimento	29.8	14.7	0.49	0.4	82.3	69
All vegetables	31.2					

Notes: Data related to the percentage of total production that is lost post-harvest. *CV* is coefficient of variation (standard deviation divided by average). *N* is sample size.
Source: authors' calculations using PAPA data.

Table 3 reports how PHL for vegetables are distributed among the different on-farm post-harvest stages including harvesting, drying, storage, and transport. The results show that, in the case of vegetable products, the losses occur mainly at the time of harvesting in the field, especially for pimentos and tomatoes, which have the highest loss rate of 17.7% and 16.7% respectively. Regarding onions, the loss rates during drying were 9.7%, even though they remain lower than the 12.6% losses during harvest. Indeed, drying has for a long time been a major challenge for onion producers since in the perception of Senegalese consumers the local onion is filled with water, which poses a defect in the drying of the product.

Table 3: On-farm post-harvest losses in specific stages for vegetable crops in Senegal in agricultural season 2015/16

	Step	Average	Standard deviation	CV	Minimum	Maximum	N
Onion	% harvest loss	12.6	12.4	1.0	0.0	66.4	507
	% drying loss	9.7	19.5	2.0	0.0	95.5	507
	% storage loss	5.2	14.8	2.8	0.0	91.5	507
	% transport loss	4.7	16.9	3.6	0.0	89.5	507
	Total	32.1	15.9	2.4	0.0	85.7	507
Tomato	% harvest loss	16.7	16.9	1.0	0.0	85.7	149
	% drying loss	7.2	21.9	3.0	0.0	98.8	149
	% storage loss	2.2	9.9	4.4	0.0	59.6	149
	% transport loss	2.4	6.7	2.8	0.0	47.1	149
	Total	28.6	13.8	2.8	0.0	72.8	149
Pimento	% harvest loss	17.7	15.5	0.9	1.6	66.6	69
	% drying loss	5.0	17.2	3.5	0.0	89.6	69
	% storage loss	2.0	11.1	5.6	0.0	85.7	69
	% transport loss	5.1	14.8	2.9	0.0	87.2	69
	Total	29.8	14.7	3.2	0.4	82.3	69

Notes: CV is coefficient of variation (standard deviation divided by average). N is sample size. Harvest loss is the loss in the field after harvest but before the crop arrives at the home for drying. Drying occurs at home because if the product is left in the field, there are risks of stealing or animals tramping or eating the crop.
Source: authors' calculations using PAPA data.

To run the PHL elimination scenario in IMPACT-SIMM, we required data on PHL and the total value of vegetable production. Data on PHL were sourced from the PAPA survey and reported the percentage of each vegetable crop produced that was lost after harvest but before consumption or sales, which was 32.1% for onions, 28.6% for tomatoes, and 29.8% for pimentos. The total value of vegetable production was based on national statistical data from total production and market price using national statistics from FAOSTAT in 2016 and was $133,284,091 for onions, $37,318,428 for tomatoes, and $13,235,455 for pimentos. Using the percentual PHL of each crop from Table 2 and the above total values of production gave a weighted average PHL of 31.22%. We used this 31.22% in our PHL elimination scenario, with results reported in Table 4.

5.2. Simulation results and discussion

Simulation results in Table 4 show that the elimination of PHL of vegetables has a direct effect on 1) the quantity of products available for either consumption or net sales and 2) imports of vegetables. In fact, following the elimination of PHL in our calculations, the quantity of domestic vegetable production that became available for consumption or sale rose from 278,000 tons to 404,000 tons. Consequently, the decline in PHL would have a positive effect on household vegetable consumption or household income, or both. In addition, the increase in food availability constitutes an important dimension of food security. Thus, increasing the availability of vegetables increases one component of food security for vegetable producers in Senegal.

The fall in PHL also leads to a 21.74% drop in imports, from 584,000 tons to 457,000 tons. This reduction in imports leads to a reduction in the trade deficit, which is in chronic deficit in Senegal. It would avoid the foreign exchange losses and improve the balance of payments of the Senegalese economy. The 31% reduction in post-harvest losses directly translates into 31% more value of total supply (278,000 tons minus 404,000 tons divided by 404,000 tons) (Table 4). An effect of more supply is that fewer imports are needed to meet domestic consumption demands with an elimination of PHL reducing imports by 127,000 tons.

Table 4: Simulated effect of changes in post-harvest losses for vegetables in Senegal

Indicator	Units	Baseline	Post-harvest loss elimination scenario
Post-harvest loss	% of on-farm total production	31.22	0
Domestic production	000 tons	404	404
Total supply available for sales or consumption	000 tons	278	404
Net imports	000 tons	584	457
Producer price	$/ton	574	574
Value of total supply available	$ million	160	232

Source: Post-harvest loss data from PAPA survey data reported in Table 2, all other data are from authors' calculations using IMPACT-SIMM for simulation year 2016. $ are 2005 constant US dollars.

The IMPACT-SIMM results suggest that eliminating all PHL for vegetables in Senegal would increase the total value of supply by $72 million and reduce imports by 127,000 tons. $72 million is the benefit of removing all PHL for vegetables, if the cost to achieve this was less than $72 million, it may warrant more examination in an overall investment plan for Senegal within the agriculture sector. Even if the net benefits are positive, other investments may also deliver positive net benefits and these would be needed as part of any comprehensive investment analysis.

The Senegalese government would thus benefit from implementing a plan to reduce PHL to be in line with SDG target 12.3. To this end, Adel (2013) proposes three strategies for reducing PHL in the value chains of perishable products, including (i) the application of current knowledge to maintain the cold chain of perishable horticultural products and the improvement of handling systems, (ii) the investment in adequate infrastructure to improve the performance of marketing systems and thus overcome socio-economic constraints, and (iii) the consolidation and vertical integration between producers and distributors of horticultural products.

On the application of conservation and storage technologies for vegetable products, our surveys show that efforts must be made to raise awareness and facilitate access for producers since only 10.18% of the surveyed farmers use specific storage methods including storage in bags, crates or outdoors (Table 5). Among those who use these technologies, the majority of onion growers (68.46%) say they store their products in bags. Among tomato producers, produce is usually stored in crates and delivered directly to the industry, while for pimento, bulk storage seems to predominate. However, with the application of chemicals for storage and sale shortly after harvest, the adoption of adequate storage technologies is one of the main strategies implemented by smallholders to reduce PHL (Affognon et al., 2015; Abdoulaye et al., 2016). Gains from adopting appropriate technologies can lead to a substantial reduction in losses if properly implemented but may sometimes require a scale of production that excludes smallholders (Rosegrant et al., 2015).

Table 5: Statistics on storage techniques and areas

		N	%
% using storage		149	10.18
Storage techniques			
	Bulk storage	44	29.53
	Bags	102	68.46
	Crate	44	29.53
Storage area			
	Hangar	21	14.09
	Outdoors	96	64.43
	Hut	5	3.36
	Ventilated room	2	1.34
	Cold room	0	0

Source: authors' calculations using PAPA data.

The use of adequate storage facilities for perishable products such as cold or ventilated rooms seems limited (Table 5). Indeed, the overwhelming majority of producers keep their horticultural products outdoors in sheds or huts. Because vegetables are perishable and cold or ventilated rooms on-farm are limited (perhaps due to the small volume for production per farmer), rapid access to the cold or ventilated rooms at the point of sale seems critical to reduce PHL. However, to increase the technical platform for the conservation and packaging of horticultural and animal products, the Government of Senegal inaugurated, in July 2018, a national market laid out over 24 hectares in Diamniadio and has stores equipped with cold rooms in addition to a phytosanitary laboratory and a common cold room of 750 m^2. With a total cost of CFA-Franc 55 billion, the national market has a triple objective of reducing PHL and regulating prices of agricultural products as well as promoting exports by offering producers and wholesalers high-performance facilities and the best conditions for produce conservation. It should be noted, however, that these infrastructures are still slow to function. Yet, Beune (2018) identifies market access and functional infrastructure as a critical success factor for PHL prevention. Indeed, if these forms of access to roads and infrastructure as well as the connectivity of actors are improved by means of investments in infrastructures, the methods of prevention of PHL are more likely to be economically interesting to farmers. Investments in roads would help reduce PHL and also deliver other benefits as the roads are used by more than just vegetable producers. In this way, improved roads can help farmers set up nonfarm businesses and have better access to employment opportunities in towns.

From an organizational point of view, the market gardening sectors of Senegal have long been perceived as success stories. Indeed, Duteurtre and Dieye (2008) identify the onion and industrial tomato sectors as concerted regulatory modes involving a dialogue between actors through consultation frameworks between state and inter-professional organizations. However, it should be emphasized that these dialogue frameworks are essentially aimed at regulating the prices of agricultural products and therefore include vertical integration between producers and distributors of products in order to reduce PHL.

6. Conclusion

Our study used household survey data to evaluate the extent of PHL for Senegal's main vegetable products, notably onions, pimentos, and tomatoes, and then simulate in IMPACT-SIMM the effect of a reduction in PHL on 1) the economic value of vegetable supply available for consumption or sales and 2) international trade. We gathered three conclusions from our study. First, vegetable growers experience substantial PHL, with losses estimated at 31.2% of produce between harvesting and marketing. Even though means exist for these farmers to reduce their PHL, we found that almost no farmers used cold or ventilated storage on-farm, which is detrimental to perishable crops and places pressure on farmers to quickly consume their vegetables or send them to market. Second, simulation results suggest that eliminating all PHL for vegetables in Senegal would increase the total value of supply by $72 million and reduce imports by 127,000 tons. If properly implemented, appropriate storage and conservation technologies could lead to a substantial reduction in vegetable PHL. To this end, the government could consider options to increase access to financing in order to enable smallholder farmers to invest in storage and conservation technologies, raise awareness and popularize knowledge to maintain the cold chain of perishable vegetable products, to invest in adequate infrastructure, and improve the vertical integration between producers and distributors of vegetable products. Third, to properly evaluate the role of reducing PHL, detailed information on costs would be required as trade-offs exist in investment prioritization. Here investing in roads warrant a closer investigation, as investments in road construction may reduce PHL if farmers can access markets faster.

References

Abdoulaye, T. et al., 2016. Postharvest Loss of Maize and Grain Legumes in Sub-Saharan Africa: Insights from Household Survey Data in Seven Countries. *Purdue Extension: Agricultural Economics,* pp. 1-4.

Adel, A. K., 2013. Postharvest Technology of Horticultural Crops – An Overview from Farm to Fork. *Ethiopian Journal of Applied Science Technology,* Special Issue (No.1), pp. 1-8.

Affognon, H., Mutungi, C., Sanginga, P. & Borgemeister, C., 2015. Unpacking Postharvest Losses in Sub-Saharan Africa: A Meta-Analysis. *World Development,* 66(27), p. 49–68.

ANSD, 2013. *Deuxième enquête de suivi de la pauvreté au Sénégal (ESPS-II 2011). Rapport définitif,* Dakar: Agence Nationale de la Statistique et de la Démographie.

ANSD, 2013. *Recencement Général de la Population de l'Habitat de l'Agriculture et de l'Elevage,* Dakar: Agence Nationale de la Statistique et de la Démographie-République du Sénégal.

ANSD, 2014. *Recensement Général de la Population et de l'Habitat, de l'Agriculture et de l'Elevage (RGPHAE),* Dakar: Agence Nationale de la Statistique et de la Démographie.

ANSD, 2016. *Situation Economique et Sociale,* Dakar: Agence Nationale de la Statistique et de la démographie.

ANSD, 2019. *Situation Economique et Sociales (SES),* Dakar: Agence Nationale de la Statistique et de la Démographie.

Bank, W., 2014. *Situation Economique du Sénégal: Apprendre du passé pour un avenir meilleur,* Dakar: World Bank Group Maocroeconomics and fiscal management.

Bank, W., 2014. *Situation économique du Sénégal: Apprendre du passé pour un meilleur avenir,* Washington: World Bank Group.

Beune, R., 2018. *Post-Harvest Loss Prevention Measures; Farmer Income Lab Intervention Quick Scan,* Wageningen: Wageningen University & Research. Report WCDI.

Chegere, M. J., 2017. *Post-Harvest Losses, Intimate Partner Violence and Food Security in Tanzania,* Tanzania: Doctoral Disertation.

Corrado, S. et al., 2019. Food waste accounting methodologies: Challenges, opportunities and further advancements. *Global Food Security,* Volume 20, pp. 93-100.

Davis, K. et al., 2016. Meeting future food demand with current agricultural resources. *Global Environmental Change,* Volume 39, pp. 125-132.

Diop, A. D., Sangaré, S. K., Ouedraogo, S. N. & Ouedraogo, S. J., 2016. *Réduction des pertes post-récolte au sahel et en Afrique de l'Ouest : un enjeu majeur pour la sécurité alimentaire,* Bamako (Mali): Institut du Sahel (INSAH/CILSS).

Diouf M., 2016. "*La tomate industrielle du Sénégal: une filière en danger*". Bulletin d'analyse économique: Centre de Gestion et d'Economie Rurale de la Vallée (CGERV)

Duteurtre, G. & Dieye, P., 2008. *Les organisations interprofessionnelles agricoles au Sénégal : de nouveaux outils de régulation des marchés ? ».* Agence Française de Développement éd. Dakar: Bureau d'analyses macro-économiques de l'Institut sénégalais de recherches agricoles (Isra-Bame).

Eigenbrod, C. & Nazim, G., 2015. Urban vegetable for food security in cities. *A review Agronomy for Sustainable Development ,* Volume 35, p. 483–498 .

FAO, 2008. *An Introduction to the Basic Concepts of Food Security. Rome: . ,* Rome, http://www.fao.org/3/a-al936e.pdf [Accessed March 19, 2019]: Food and Agriculture Organization of the United Nations.

FAO, 2011. *Global Food Losses and Food Waste – Extent, Causes and Prevention,* Rome: FAO.

FAO, 2014. *Food Loss Assessments: Causes and Solutions, Case Studies in Small-scale Agriculture and Fisheries Subsectors, Global Initiative on Food Loss and Waste Reduction. Kenya case studies,* Rome: FAO.

FAO, 2019. *The State of Food Security and Nutrition in the World 2019: safeguarding against economic slowdowns and downturns,* Rome: FAO.

Fischler, M. et al., 2011. *POSTCOSECHA Programme Central America,* Guatemala: Swiss Agency for Development and Cooperation.

Foresight, 2011. *The Future of Food and Farming: Challenges and choices for global sustainability,* London: The Future of Food and Farming Final Project Report. The Gouvernent Office for Science.

Gouel, C. & Guimbard, H., 2018. Nutrition Transition and the Structure of Global Food Demand. *American Journal of Agricultural Economics,* Volume 101, pp. 383-403.

Gustavsson, J. et al., 2011. *Global food losses and food waste,* Rome: FAO.

Hengsdijk, H. & de Boer, W. J., 2017. Post-harvest management and post-harvest losses of cereals in Ethiopia. *Food Policy,* Volume 9, pp. 945-958.

Kaminski, J. & Christiaensen, L., 2014. Post-harvest loss in sub-Saharan Africa—what do farmers say?. *Global Food Security,* 3(3), pp. 149-158.

Kitinoja, L., Tokala, Y. V. & Brondy, A., 2018. Challenges and opportunities for improved postharvest loss measurements in plant-based food crops. *Journal of Postharvest Technology,* 6(4), pp. 16-34.

Kughur, P.G. & Iornenge, G.M. & Ityonungu, B.E., 2015. Effects of Postharvest Losses on Selected Fruits and Vegetables Among Small-scale Farmers in Gboko Local Government Area of Benue State, Nigeria. *International Journal of Innovation and Scientific Research,* 19(1), pp. 201-208.

Lipinski, B. et al., 2017. *SDG Target 12.3 on Food Loss and Waste: 2017 Progress Report,* Amsterdam: Ministry of Economic Affairs of the Kingdom of the Netherlands.

Lundqvist, J., de Fraiture, C. & Molden, D., 2008. *Saving water: from field to fork—Curbing losses and wastage in the food chain,* Stockholm, Sweden: SIWI: In SIWI policy brief.

Niang, Y., 2019. *Postharvet handling of Onion in Senegal.* Rural Development Administration, Korea éd. Dakar: National Institute of Horticultural and Herbal Science.

Omotajo, O. R., Olaniyan, O. & Mudahunga, J.-C., 2018. Effects of Agribusiness Investments on Postharvest Losses and Food Security in Sub-Saharan Africa: Evidence from Maize and Beans Value Chains in Nyagatare District, Rwanda. *IFAD Working papers,* pp. 1-16.

Pelletier, D., 1997. *Étude de faisabilité. Synthèse de l'analyse économique,* Thies/Senegal: PAEP/CECI/ACDI.

Pinstrup-Andersen, P., 2009. Food security: definition and measurement. *Food Security ,* 1(1), pp. 5-7.

PRACAS, 2014. *Programme de Relance et d'Acceleration de la Cadence de l'Agriculture Sénégalaise,* Dakar: République du Sénégal.

PSE, 2014. *Plan Sénégal Emergent,* Dakar: République du Sénégal.

Robinson, S. et al., 2015. *The International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT): Model description for version 3,* Washington: International Food Policy Research Institute (IFPRI).

Rosegrant, M. W., Magalhaes, E., Valmonte - Santos, R. A. & Mason–D'Croz, D., 2015. *Returns to Investment in Reducing Postharvest Food Losses and Increasing Agricultural Productivity Growth: Post-2015 Consensus,* Washington D.C.: International Food Policy Research Institute.

Sharma, S., 2016. Economic analysis of post-harvest losses in onion in jodhpur district of rajasthan. *International Journal of Research in Business,* 4(3), pp. 119-124.

Sheahan, M. & Barrett, C. B., 2017. Review: Food loss and waste in Sub-Saharan Africa. *Food Policy,* pp. 1-12.

Shee, A. et al., 2019. Determinants of postharvest losses along smallholder producers maize and Sweetpotato value chains: an ordered Probit analysis. *Food Security,* pp. 1-19.

Tefera, T., 2012. Post-harvest losses in African maize in the face of increasing food shortage. *Food Security,* 4(2), pp. 267-277.

Van den Broeck, G., Kaat, V. H. & Miet, M., 2018. Horticultural exports and food security in Senegal. *Global Food Security,* Volume 17, p. 162–171.

Van Rensburg, J. et al., 2007. African leafy vegetables in South Africa Water. 33(3), p. Special Edition.

Van Wyk, B. & Gericke, N., 2000. *People's Plants: A Guide to Useful Plants of Southern Africa,* Pretoria, 352: Briza Publications.

Willett, W. et al., 2019. *Food in the Anthropocene : the EAT–Lancet Commission on healthy diets from sustainable food systems,* s.l.: The Lancet Commissions.

World Bank, 2018. *Systematic country diagnostic of Senegal,* Washington: World Bank Group.

Ye, L., Tang, H., Wu, W., Yang, P., Nelson, G.C., Mason-D'Croz, D. & Palazzo, A. (2014). Chinese Food Security and Climate Change: *Agriculture Futures Economics:* Vol. 8, 2014-1. http://dx.doi.org/10.5018/economics-ejournal.ja.2014-1

Zorya, S. et al., 2011. *Missing food: the case of postharvest grain losses in sub-Saharan Africa,* Washington: World Bank.