Assessing the Economic Impacts of Tomato Integrated Pest Management in Mali and Senegal

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Abstract

This study assesses the research benefits of IPM technologies and management practices aimed at reducing the virus problem in tomatoes in West Africa. Surveys are conducted with producers, extension agents, scientists, and other experts to obtain information and economic surplus analysis is used to project benefits over time. The determinants of adoption are assessed using a probit model. Results show that adoption of the host-free period reduced the amount of insecticide sprays by 71% and the production cost by $200/ha in Mali. The cost-benefit analysis indicated that the use of virus-tolerant seeds generated profits ranging from $1,188 to $2,116/ha in Mali and from $1,789 to $4,806/ha in Senegal. The likely factors influencing adoption of the technologies in both countries are the frequency of extension visits, farmer's field school training, gender, education, seed cost, tomato area, and experience in tomato losses. The benefits in the closed economy market vary from $3.4 million to $14.8 million for the host-free period, $0.5 million to $3 million for the virus-tolerant seeds, and $4.8 million to $21.6 million for the overall IPM program. In the same order, the benefits under the open economy market range from $3.5 million to $15.4 million, $0.5 million to $3million, and $5 million to $24 million. The distribution pattern indicates that producers gain one-third and consumers two-thirds of the benefits. Our results support policies aiming to increase the adoption rate or the expected change in yield.

To my wife Blandine-Armande, and my children Juarez-Gracias, Cornelia-Loriane, and Mahuna-Berenice, your patience and unconditioned love are my comfort and my strength.

~_~_~_~_~_~_

To Mom and Dad, thanks for your support.

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Abbreviations and acronyms

ABSPII : Agricultural Biotechnology Support Project II

ANCAR : Agence Nationale de Conseil Agricole et Rural

AVRDC : Asian Vegetable Research and Development Center (The World Vegetable Center)

FAO : Food and Agriculture Organization of the United Nations

FAOSTAT : Food and Agriculture Organization Corporate Statistical Database

FFS : Farmer Field School

HFP : Host-Free Period

IER : Institut d'économie rurale

IICEM : Initiatives Intégrées pour la Croissance Economique au Mali

IITA : International Institute of Tropical Agriculture

IPM : Integrated Pest Management

IPM-CRSP : Integrated Pest Management- Collaborative Research Support Program

USAID : United States Agency for International Development

USAID/WARP: USAID/West Africa Regional Program

TYLCV : Tomato Yellow Leaf Curl Virus

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1. Introduction

1.1. Problem

Tomato virus has become a severe constraint to tomato production in West Africa during this last decade. The causative agent of this virus has been identified as a germinivirus: the tomato yellow leaf curl virus (TYLCV) (Kung, 1999). This causal virus has reduced the yield and the area under tomato production throughout the region. The virus is transmitted by the sweet potato whitefly, *Bemisia tabaci* (Gennadius) (Noussourou, 2007). Production losses caused by germiniviruses can be very high (e.g. 100%). Most producers rely on an intensive use of insecticides to control the virus vector, *Bemisia tabaci*. As viruses are particularly difficult to manage because of the high rate of mutation to other more resistant forms, the amount of pesticide used has become greater and greater. This situation has lead to an increase in production costs and therefore to an increase in the market price, and to a shift out of tomato production especially during the period when the incidence of the virus is highest.

To reduce the negative impact of the virus and the oversupply in some months and undersupply in others, tomato production needs to be expanded from approximately three months (April to June) to a minimum of six months. This expansion implies that there is a need to identify varieties with disease resistance. Some disease-tolerant varieties have been developed through collaborative research programs with USAID support in Mali. USAID-funded activities are implemented to address tomato virus problems in West Africa. One of the activities is an effort by the IPM-CRSP (UC Davis) to evaluate conventional varieties with Tomato Yellow Leaf Curl Virus (TYLCV) resistance as part of a program that also includes a host-free period and other practices to reduce the pressure of the virus and its vector. The other most important activity includes the development of a transgenic tomato.

This first effort has resulted to the identification of eight tomato varieties based on their resistance to the virus from experiments in Mali from 2004 to 2006. Within these varieties, two of them, Gempride and H8804, have the lowest disease incidence and were considered resistant to the complex of viruses. Six others varieties including Shasta, Mongal F1, H6703, H9425, H6503, and H9881 were moderately resistant, as they were superior to the susceptible checks, cultivars Roma VF and UC82 (Noussourou, 2007, op cit). Further development of this program has been explored in the context of establishing a breeding program to introduce conventional TYLCV resistance into locally adapted varieties.

The second funded activity includes the development of a transgenic tomato, resistant to TYLCV. This program is supported by USAID/Mali and USAID/WARP through the Agricultural Biotechnology Support Project II (ABSPII) and implemented by UC Davis, Cornell, AVRDC, and the *"Institut d'Economie Rurale"* (IER) in Mali. ABSPII has been screening tomato cultivars for resistance to TYLCV and the screening program resulted in the identification of several partially resistant tomato cultivars.

In addition to genetic resistance, a host-free period or a tomato vector-free period (*cleaning out the virus from the area*) has been tested for several years now in Mali. The role of the host-free period is to eliminate the virus for a period of time and reduce the whitefly population, the virus vector. In Senegal, the net-protected nursery technique was introduced by the research and extension office (ANCAR). The net-protected nursery consists of protecting the tomato nursery from the virus vector using a net, since tomato plants at this stage are more susceptible to the virus. The host-free period technique and the net-protected nursery, aim to reduce the physical contact between the insect vector and the plant, and therefore to reduce the yield loss engendered by the virus.

Today, TYLCV is spreading in West Africa and is one of the major constraints that cause significant economic damage to tomatoes. For example, in the Upper East Region in Ghana, devastating tomato losses caused by TYLCV have been observed since 2002. The country has to import tomatoes from other countries in West-Africa, especially during the dry season when the incidence of the virus is high (Horna et *al.* 2008). As viruses continue to evolve to overcome resistance, there will be an ongoing need to develop novel approaches to combat them in order to offset the serious economic problem to producers. The development of a novel transgenic product to address the major disease and virus problems would be one of the key actions that could help improve and sustain rural livelihoods in the region. However, an assessment is needed of the economic benefits to producers and to the country from adopting IPM strategies and the willingness of producers to use virus-tolerant tomato seeds.

1.2. Objectives

The purpose of this study is to i) evaluate the effectiveness of the host-free period and the net-protected nursery on increasing tomato yield and on reducing pesticide use, ii) analyze determinants of adoption of IPM strategies; and iii) assess the joint economic benefits to producers and consumers of the development of IPM cropping strategies and the virus-tolerant varieties.

1.3. Research hypotheses

The following hypotheses are tested

1.a. The use of IPM strategies (host-free period, net-protected nursery, and virus-tolerant varieties) reduces tomato losses and pesticide costs by at least 50%.

1.b. The adoption of IPM strategies improves farm household income by generating significantly higher profits for producers

1. Producers' gender, level of education, farm size, previous FFS training for IPM, and contact with extension are key factors influencing positively the adoption of IPM strategies.

2. The development of virus-tolerant seeds associated with IPM cropping practices to control whitefly infestation on tomato induces a significant change in total economic surplus and improves both producer and consumer welfare.

For this hypothesis, we use the virus-tolerant tomato varieties currently in use as a proxy to evaluate the potential benefits of transgenic seeds. Producers and consumers welfare is assessed using an economic surplus approach. The benefits resulting from the technologies are presented under both a closed and an open economy. Three different market scenarios are considered for the evaluation. Scenario 1 assesses the research-induced benefits for IPM cropping strategy: the host-free period; scenario 2 assesses potential benefits for virus-tolerant tomato varieties. This scenario is used as a proxy for assessing the potential benefits of the transgenic seeds once released. Scenario 3 presents the research benefits for the overall IPM program (both cropping strategies and development of virus-tolerant tomato seeds) in the region.

1.4. Organization of the thesis

The following chapter presents an overview of the literature on tomato virus problems in West Africa, the theories of adoption of agricultural technologies, and the use of economic surplus analysis to evaluate research benefits. Chapter 3 discusses the methodological framework used for data analysis. In this section, sampling and data collection techniques, and the analytical and empirical frameworks used for data analysis are described. The main findings are presented in chapter 4. Chapter 5 presents the conclusion and derives some policy implications.

2. Background

2.1. Tomato virus problem and management

Tomato virus is one of the major constraints to tomato production. Previous research (Zhou and *al*., 2008) identified two major types of viruses in West Africa during the last decade: Tomato leaf curl virus and Tomato yellow leaf curl virus. The most common virus widely spread is the tomato yellow leaf curl viruses (TYLCV). The tomato yellow leaf curl viruses are transmitted by the whitefly: *Bemissia tabaci*. Plants infested by the viruses show severely stunted growth, twisted, curled and discolored leaves; and reduced yields. This virus has plagued tomato production, severely reducing yields and, in some cases, making the cultivation of tomato no longer economically viable (Gilbertson and Shetty, 2006). A collection of tomato plants showing representative symptoms of virus infection was analyzed using biotechnology tools: DNA probes and polymerase chain reaction (PCR). Most of these samples were infected with germinivirus, which was consistent with the presence of whiteflies on tomatoes (Gilbertson and Shetty, 2006, op cit). A baseline survey conducted in 2006 (Nouhoheflin and *al*., 2007) revealed that tomato producers were aware that the viruses were transmitted by whiteflies, and that they relied on intensive use of insecticides to control the virus and its vector due to a lack of alternative control methods. Some producers reported that before the identification of the host-free period, tomato production was almost not possible, as the population of whiteflies was high, and the incidence of the virus widespread. The effect of TYLCV on production was also observed in other regions across the world. For example, in Israel, despite almost daily spraying with insecticides, 100% yield losses have often been recorded in cases where the whitefly populations were high (Cohen & Antignus, 1994, cited by Poslton and *al*. 2007). In Florida, the virus was also considered as the most important pathogen of tomato where it caused crop failures and led to a rise in production costs (Lapidot & Friedmann, 2002, cited by Polston, op cit). Various alternatives have been developed to reduce the incidence of the virus. Alternatives include, but are not limited to, physical barriers such as a net-protected nursery, whitefly-proof screens, UV-absorbing plastics, the avoidance in time (or host-free period), the use of tolerant tomato varieties, and the use of virus-free transplants.

A physical barrier such as a net-protected nursery was promoted in Senegal to protect young tomato plants from the virus. Unfortunately, this technique was not well-known, nor used much by tomato producers. Similar techniques such fine-mesh screens have been used in the Mediterranean Basin since 1990 to protect tomato from TYLCV (Berlinger & Lebiush Mordechi, 1996; Cohen & Antignus, 1994). This technique became a necessity in this region due to the spread of TYLCV and its whitefly vector. The 50-mesh whitefly-proof screens significantly decreased the number of invading whiteflies in covered nets or greenhouses. Another technique used is the UV-absorbing plastics technique. This technique reduces the level of UV light in order to blind the whiteflies, as the UV light wavelength is important for their navigation. The technique can efficiently control the incidence of TYLCV.

The avoidance of the TYLCV for a period of time, or “host-free period,” consists of avoiding tomato production during the period when the population of the whiteflies is high. The identified period of avoidance is June-July in Mali. During that period of two months, the population of whiteflies is high and tomato production should be avoided due to the high level of virus infestation. To prevent virus re-infestation to the new plants, old plants from previous harvests should be systematically destroyed before planting the new ones. Recent data (USAID-Mali, IICEM, 2009) reveal that in

Baguineda, where the incidence of the virus is the highest in the country, 98% of the total area of 95hectares is cleaned-up before planting new plants in order to prevent virus infestation. This technique helps reduce the transmission of the virus vector across cropping seasons.

The use of virus-tolerant tomato seeds is another strategy to reduce the effect of the virus on tomato production. The most common resistant/tolerant varieties of tomato in Mali West Africa are H8804 and Shasta with a yield of 46t/ha and 33t/ha respectively, compared to 12t/ha for UC-82 and Roma VF, both sensitive to the virus (USAID-Mali-IICEM, 2009). However, the proportion of producers who rely on this approach is low due to the relatively high cost of the seeds.

The production of virus-free transplants is also another way to control virus infestation on tomato. This technique was observed in a few farms in Senegal during our surveys and can be also promoted since later virus infestation has little effect on the production.

Among these techniques, our analyses focus on the use of the host-free period, and virus-tolerant varieties, the two most common strategies used by tomato producers to control virus infestations on tomato in West Africa.

2.2. Impact assessment and adoption measure of IPM strategies

2.2.1. Assessing the benefits of IPM strategies

Measuring the impact of IPM technologies requires an aggregate assessment of the research program. Defining what is meant by IPM and determining its degree of adoption are frequently the first steps in an evaluation (Norton, Moore, et *al.,* 2005). This evaluation is complex because IPM technologies involve several individual practices or strategies. In this study, IPM technologies include (a) a whitefly management system, (b) surveys of virus diseases, and (c) screening of varieties for virus resistance. The economic impact assessment of integrated programs refers to the economic analysis of the full range of the consequences, immediate and long-term, intended and unanticipated, of the introduction of a new technology, project, or research program (Porter and Rossini, 1984). Two different methods are used to examine the economic impact of IPM technologies: before the research is completed (*ex-ante* assessment), and after the technologies are released and adopted (*ex-post* assessment). The *ex-post* impact assessment provides information on research results to justify requests for continuing funds and support. *Ex-post* assessment may contain elements of *ex-ante* analysis because not all benefits of a given program may have been realized up to the point when the *ex-post* evaluation takes place. Most evaluation studies have used the *ex-post* approach. This study uses *ex-post* economic impact assessment. The *ex-post* evaluation is performed for IPM strategies such as the host-free period and the virus-tolerant tomato varieties used as a proxy for the development of transgenic tomatoes. This evaluation provides information on the potential economic benefits of the development of transgenic seeds and its impact on total economic surplus over years.

The economic impact of a host-free period is assessed through cost savings in production due to the reduction of the amount of insecticides used, and the gain resulting from yield increment. Virus-tolerant seeds are evaluated by calculating the change in yields with respect to the virus-sensitive ones. Other benefits of IPM strategies may include externalities such as technology and price spillovers (Alston and *al.* 1995, p.294). Price spillovers occur when a change in technology in one country affects the price of the tradable good in other countries. In the case of tomato production in Mali, the technical change resulting from adoption of IPM strategies may provoke a price spillover in the rest of the West African countries. Technology spillovers may occur (even locally) and are considered as positive externalities because the adoption of IPM strategies leads to a significant reduction in agricultural insecticides applied. Pollution in both surface and underground water as well as the amount of pesticide residues on tomatoes may be reduced. The premium associated with this improvement can be evaluated by assessing consumers' willingness to pay for tomatoes produced with reduced amounts of pesticides. This premium is not evaluated in this study and may be considered in future research. The total benefits of IPM strategies addressed in this study are the benefits from the adoption of a host-free period and of the virus-tolerant seeds. The difference in pesticide expenditures between users and non-users of a host-free period strategy, and the associated yield gain are used to measure the benefits of adopting that strategy. Similarly, the benefits from adoption of virus-tolerant seeds are assessed by considering yield differential between virus-sensitive and virus-resistant seeds plus the difference in production costs.

2.2.2. **Adoption of host-free period and net-protected nursery**

Since its implementation in 2004 in the irrigated area of Baguineda (project site) in Mali, the adoption of a host-free period strategy has occurred in almost all the villages of this region. With a total number of 20 producers from two villages in 2004, the first year of the adoption of the strategy, the host-free period strategy expanded to 16 villages in 2006 with a total of 420 tomato producers (Noussourou, 2007). In 2008, the strategy spread to all the 22 villages in Baguineda (USAID/IICEM, 2009). Meanwhile, more than 500 producers and 40 extension agents were trained on the efficient use of the strategy. The aim of this training was to expand the adoption to a large number of producers. The number of producers reached in 2009 was 1,999 (cf. tables 2.1 & 2.2).

Table 2.1: Adoption path of host-free period in Mali

Years	# Producers	# Villages	Area covered (ha)
2003	-	-	-
2004	20	2	-
2005	330	11	-
2006	420	16	71.5
2007	-	22	95.38
2008	1999	22	74.07
2009	-	22	106.53

Source: Noussourou, 2007; USAID/IICEM 2009

Table 2.2: Adoption of host-free period in Mali in 2008

	Male	Female	Total
Population size of the irrigated area of Baguineda	13576	12976	26545
Number of producers			3000
Number of producers who adopted the host-free period			1999
Number of extension agents trained on IPM strategies	37	3	40
Number of producers trained on IPM strategies	409	100	509

Source: USAID/IICEM, 2009 (unpublished report)

With respect to tomato acreage, the host-free period strategy was observed on 93 hectares out of a total area of 95 hectares of tomato production in 2008 (table 2.3); or 98% of the total area covered. Prior to the implementation of the strategy, tomato production was not possible in this location, as the incidence of the virus vector (whiteflies) was high (Noussourou, 2007). The implementation of the host-free period and its effectiveness demonstrated to tomato producers that tomato production is still possible in the location. The adoption significantly raised the volume of tomato production from 1,265 tons in 2006 to 2,035 tons in 2009, which corresponds to a proportionate change of 61%. Likewise, tomato yield has increased from 17.65t/ha in 2006 to 26.95 t/ha in 2008. The low yield observed in 2009 (19.11t/ha) was caused by a limited supply of water due to maintenance of the irrigation system. Table 2.3 indicates the trends in tomato area, yield and production over years. With respect to the amount of insecticides used, recent data showed that the use of the host-free period strategy led to a significant reduction in the amount of sprays during the growing period. The number of sprays decreased from 7-10 sprays to 2-3, or 71% of reduction. Similar results were found in Indonesia where adoption of IPM strategies for rice farmers has reduced the amount of pesticides used by approximately 56%, and increased rice yield by approximately 10% (Resosudarmo, 2008). Prior to this study, data from the Indonesian IPM National Program Monitoring and Evaluation Team in 1993 showed that the adoption increased rice producers' income by approximately 50%.

Table 2.3: Trends in tomato area, yield and production

Years	Area (ha)	Yield (t/ha)	Production (t)
2003	13.56	-	-
2004	13.16	-	-
2005	65	-	-
2006	71.5	17.65	1262.33
2007	95.38	29.89	2851.16
2008	74.07	26. 95	1996.11
2009	106.53	19.11	2035.84

Source: OPIB, 2009

In Senegal, the net-protected nursery strategy delayed virus infestation and reduced the incidence of the whiteflies later in the growing season. To date, few tomato producers rely on the use of this strategy in Senegal. The use of a similar technique in Cambodia and Thailand was not conclusive regarding its impact on the reduction of virus incidence. In Cambodia, experiments conducted by Kung (1999) of the effects of the net-protected nursery on tomato production revealed that there is no significant difference in tomato yield using the net and the one grown without net protection. On the other hand, the study conducted by AVRDC-Thailand (2000) found that the use of a barrier controlled the whitefly throughout the tomato crop duration. The whitefly population was 67% lower inside the barrier compared to the open field, and the TYLCV incidence was half as much within the barrier as in the open field. The Kung finding was explained by the low whitefly population during the seedling stage of his experiment. The effect should be tested when whitefly population is higher.

2.2.3. **Adoption of virus-tolerant tomato varieties**

Virus-tolerant tomato varieties are introduced into field trials in Mali to assess their susceptibility to the TYLCV. The main virus-tolerant varieties identified and commonly used for virus control include Shasta and H8804. These varieties are now released for large multiplication for extensive use. In 2009, 555 tomato producers from seven districts (including 501 in Baguineda) used either Shasta or H8804 (USAID/IICEM, 2009). Results from farm trials reveal that Shasta and H8804 recorded yields of 64.3 t/ha and 32.7 t/ha respectively during the first production season (August-November); and 27t/ha and 19.2 t/ha respectively during the second production season (December-April). In Senegal, the most common tomato varieties tolerant to virus are Gempride and Mongal F_1. Other varieties include Mboro, Yaqui, orbite, Nadira, and Rio fuego, but their susceptibility to TYLCV is not yet proven. Data from the tomato cannery at Saint-Louis (Senegal) revealed that the average yield observed ranges from 25t/ha to 40t/ha for Gempride.

2.3. Household decision model and adoption of new agricultural practices

The decision of a household to adopt new agricultural practices depends on the utility it derives from those technologies. This decision is a discrete choice in which individuals or households must choose between the new agricultural practice and the previous one. With respect to the uncertainty associated with new technologies, individuals or households base their decision on expected utility rather than expected profit. This theory is largely accepted (Anderson et *al.*, 1977) for producers when their aversion to risk and beliefs play an important role in the decision-making process. Households maximize their utility based on their initial endowment, the knowledge they possess and the constraints associated with the use of these resources (Anderson et *al.*, 1977). That is, the decision to adopt occurs when the utility the household derives from the new technology is greater than the one from the previous technology. This utility is not directly observable but can be modeled according to Caviglia and Kahn, (2001); and Adesina and Zinnah (1993), using household, farm, and technology characteristics.

Previous studies (Carey, 2000; Rezvanfar and al. 2009) reveal that there are two groups of factors that influence the household decision to adopt new agricultural practices. The first group includes farmers' characteristics such as age, education, experience in farming, knowledge and awareness of the new practice, attitude toward the new practice and farmers' motivation. The second group includes farm characteristics such as farm size, income, farm profitability, and land tenure. According to Rogers (1995), technical and financial considerations have been identified from a multitude of studies as being the most likely determinants of the adoption of new agricultural practices. Determinants include the financial advantages of adoption, the complexity of the new practice, the compatibility with existing practices, the ease of trying the new practice, and how easily the results can be seen and measured. As mentioned by Barr and Carey (2000), factors affecting the adoption of new agricultural practices are related to the characteristics of the practice and to farmer beliefs, values, and social systems. Rezvanfar and *al.* (2009), while analyzing factors affecting the adoption of sustainable soil conservation practices among wheat growers in Iran, identified that growers' participation in the training associated with the practice, the information diffusion network, extension agent advice, and growers' level of awareness and knowledge were factors affecting the adoption of soil conservation practices. Rogers (1995, op. cit) concluded that early adopters have greater social participation. Early adoption is often observed when farmers belong to a community-based organization where their contact and awareness of the practice being adopted is higher. Liu Yong-gong and Qiu Guo-jun (2001) while studying factors affecting the adoption of IPM technologies on vegetable in China, identified groups of factors including producers' characteristics, extension service, inputs and outputs market, the macroeconomics environment, and IPM characteristics. The present study will lend a hand to confirm whether or not some of these factors affect adoption of IPM strategies for tomato production in West Africa.

2.4. Economic surplus approach for evaluating agricultural technologies

The economic surplus approach has been frequently used in recent years to assess the impact of agricultural research benefits in developing countries (Alpuerto 2008; Kostandini et *al*. 2009; Islam and Norton 2007; Hareau et *al*. 2005; Masters and *al.* 1996; and Alston, Norton, and Pardey 1995). This approach measures benefits that can be included in a benefit-cost analysis and also used to calculate the net economic benefits associated with research alternatives.

The economic surplus analysis was used by Mills (1998) to conduct an *ex-ante* economic evaluation of sorghum technology in Kenya. The author presented a process for *ex-ante* research evaluation with a dynamic, spatial multi-market model under constraints such the agro-ecological conditions for technology generation and adoption, and the commodity market-structure. In that paper, the author showed to what extent research-induced reductions in production costs may reduce market prices and change the distribution of benefits between consumers and producers. He calculated research benefits for specific research themes within Agro-ecological zones of Kenya. The results demonstrated that potential research benefits can vary dramatically across program research target zones, and that the population-induced demand growth will have the greatest influence on future sorghum markets.

An economic surplus approach is also a strong decision-making tool which captures both researchers' and policymakers' interests. Tabor and Faber (1998), show this advantage and argue that a key problem in agriculture is that researchers tend to start their analysis of a problem with the natural resource whereas policymakers tend to begin from the social consequences. As a result, solutions developed by scientists may have limited appeal to policy-makers and problems identified by policymakers may be considered to require little research by scientists. It seems unlikely that this problem of perspective can ever be fully resolved, but at least economic surplus can give some commonality. Another very important advantage of economic surplus is that it can take into consideration un-priced resources, precisely resources for which markets do not exist. The fact that a resource is not traded in a market and hence has no price does not mean that it is of no value.

Application of the economic surplus approach on the research programs has shown meaningful results in developing countries. The approach was used to project the welfare benefits of adopting *Bt* eggplant in India, Bangladesh, and the Philippines (Mishra, 2003). The welfare benefits were estimated at $411 million, $37 million, and $28 million for India, Bangladesh and the Philippines, respectively. The distribution of the benefits for consumers and producers was about 57% and 43% of the total surplus respectively. Mamaril (2002) indicated that the total welfare gain from adopting *Bt* rice in the Philippines and Vietnam would be $618.8 million ($269.6 million for the Philippines, $329.1 million for Vietnam, and, $201 million for the rest of the world). The distribution of the benefits showed that producers would capture 66.5% of the total welfare effect in both countries whereas 25.9% could go to consumers, and the remaining 3% to the rest of the world.

The economic surplus method was also used by Hareau et al. (2005) to estimate the benefits resulting from adopting transgenic rice in Asia. The author found that the Net Present Value resulting from the adoption of transgenic rice could increase with perfectly competitive markets from $1.82 million to $5.38 million in Asia. Likewise, Kostandini et al. in 2009 assessed the *ex-ante* benefits of transgenic drought tolerance research for maize, rice, and wheat across Asia and Africa, in particular in Bangladesh, India, Philippines, Indonesia, Kenya, Nigeria, Ethiopia, and South Africa. The authors showed that benefits from yield variance reductions were an important component of aggregate drought research benefits. The yield variance reductions accounted for 40% of total benefits across the countries. The annual private sector benefits were estimated at $178 million. These benefits were a significant incentive for private sector participation in transgenic drought-tolerance research. The authors also examined the *ex-ante* economic impact of transgenic drought- resistant maize breeding and conventional maize, millet and sorghum drought-resistant breeding in Kenya, Uganda, and Ethiopia. They combined an expected utility framework with a partial equilibrium model and a spatial drought risk zonation scheme to estimate benefits from mean yield increases and yield variance reductions at the market and the household levels. Results from this second estimation suggested that annual *ex-ante* benefits of $87 million, $6.8 million and $4.8 million could be generated from the public sector for a conventional breeding research on maize, sorghum and millet respectively. Private sector transgenic drought-tolerance research could also generate substantial benefits for maize producers and consumers, particularly through the reduction of yield variance arising from drought, and additional profits from intellectual property rights protection.

For our study, the economic surplus approach is used to project the benefits of adopting IPM technologies for both producers and consumers in West Africa. The distribution of the research-induced benefits among producers and consumers is also assessed over years.

2.5. Synthesis of the review

The literature provides information about the use of the IPM strategies in insect and disease control. Some studies have evaluated the impact of IPM technologies on crop productivity and estimated the benefits at both households and country levels. Benefits are expressed in terms of reduction of costs of production, improvement in yield, and generation of additional income. Though the adoption of technologies has resulted in an increase in yield and production, the effect on price depends on the size of the market and on consumers' preferences. An increase in price may occur when the demand of the good increases in size due to export demand. As the demand for food crops is almost inelastic, an increase in tomato production caused by the adoption of the IPM technologies could lead to a reduction in price in a closed market. The potential of IPM to improve both individual and social welfare, and thus to contribute to food security and poverty reduction is obvious in developing countries. However, there is limited research assessing the economic impact of IPM strategies on both producers and consumers surplus, as well as on the total economy in West Africa because IPM strategies are not yet considered as a national and regional crop protection policy. In consequence, there are limited resources and facilities devoted to the strategies in the region. The determinants of adoption are also well documented and the most likely factors affecting the adoption of IPM technologies include and are not limited to the accessibility and availability of improved seeds, the continuous usage of toxic insecticides, lack of facilities for extension agents, and limited access to credit.

This study analyzes the economic benefits of adopting IPM strategies on tomatoes in West Africa, especially in Mali and Senegal where some IPM technologies have been implemented in the recent years. The determinants of adoption, the change in production costs due to a reduction in the amount of insecticides sprayed, and the economic benefits of IPM strategies for different categories of stakeholders is not addressed in previous studies in West Africa. To date, data have shown that the use of a host-free period has significantly reduced the frequency of insecticide sprays but the quantity associated with this reduction is not estimated, nor the gain associated with this reduction. Moreover, the benefits of IPM adoption on households as well as at the national level benefit are not evaluated. This study conducts such evaluations.

3. Methods

3.1. Modeling the adoption of IPM strategies

3.1.1. **Utility function**

One of the main motives that drives producers to adopt new agricultural technologies, as mentioned previously, is utility maximization. According to Caviglia and Kahn (2001), the non observable utility function of adopting new agricultural practices is given by $U(M_{ij}, A_{ij})$ where M is a vector of household characteristics and *A is* a vector of the technology characteristics; i represents a given producer and j is the new technology. In our case, the new technology is represented by the host-free period or virus-tolerant varieties. The unobservable utility function can be written as:

$$U_{i1} = \delta_i M_{i1} + \lambda_i A_{i1} + e_{i1} \qquad (3.1)$$
$$U_{i0} = \delta_i M_{i0} + \lambda_i A_{i0} + e_{i0}$$

Where

- U_{i1} and U_{i0} represent the utility of choosing the new strategy and of not choosing the new strategy by an individual *i* respectively.
- e_{i1} and e_{i0} are the error terms with zero mean,

With respect to the utility function, the *ith* producer will adopt the new technology *j* =1, if the utility derived by adopting it is greater than the utility from the alternative technology; that is, $U_{i1} > U_{i0}$. In other words, the decision of adoption prevails if the latent variable $Z_i = U_{i1} - U_{i0} > 0$; $Z_i < 0$ otherwise.

Maddala (1986) suggested the following method to evaluate the unobserved utility:

$$Y_i = U_{i1} - U_{i0} = \delta_i (M_{i1} - M_{i0}) + \lambda_i (A_{i1} - A_{i0}) + (e_{i1} - e_{i0}) \qquad (3.2)$$
$$Y_i = x_i^{'} \beta + e_i^{*}$$

Where $x_i^{'}$ represents the vector of independent variables which are assumed to influence the outcome; Y_i, β are unknown parameters typically estimated using maximum likelihood, and e_i^* is the random error in the model.

3.1.2. **Probit model**

The decision to adopt the new strategy is a discrete choice which is assumed to follow a normal distribution. The probability of adoption is estimated using a probit model expressed as follows (Greene, 2008):

$$\Pr(Y=1)=\int_{-\infty}^{x^{'}\beta}\phi(t)dt=\Phi(x^{'}\beta)=\Phi(Z_i^*) \qquad (3.3)$$

Where

- Φ_i (x' β) is the cumulative density function evaluated at X_i β.
- $\phi(.)$ is the standard normal distribution
- x' is a vector of independent variables, some of which may be interaction terms
- β is a vector of coefficients to be estimated

Z_i^* is the expected value of the latent variable Z_i (3.2)

We assume that Z_i is a function of the vector of household characteristics (HHC), of farms characteristics (FARM), and of institution characteristics (INST). The latent variable can be written as follows:

$$Z_i = \alpha + \nu HHC + \theta FARM + \gamma INST + e \qquad (3.4)$$

and the expected value of Z_i^* as:

$$Z_i^* = E(Z_i \mid X) = \alpha + \nu HHC + \theta FARM + \gamma INST \qquad (3.5)$$

The maximum likelihood function is given by

$$\ln L(\beta) = \sum_{i=1}^{n} \{y_i \ln \Phi(x'\beta) + (1-y_i)\ln[1-\Phi(x'\phi)]\} \qquad (3.6)$$

The estimator $\hat{\beta}$ maximizes the likelihood function and is consistent, asymptotically normal, and efficient.

Marginal effect: In the probit regression model, coefficients cannot be directly interpreted as the relative contribution on the probability of adoption. The relative contribution is computed using the STATA command "dprobit" to get partial effects on response probabilities. The command "dprobit" also estimates maximum likelihood probit models, and reports the change in probability for a marginal change of each continuous explanatory variable, and the discrete change in the probability for dummies. The marginal effect or the change in $\phi(Z_i)$ relative to the change of continuous independent variables is expressed by using the chain rule:

$$\frac{\delta\phi\ (Z_i)}{\delta X_{ij}} = \left(\frac{\delta\phi}{\delta Z_i}\right)\left(\frac{\delta Z_i}{\delta X_{ij}}\right) = \phi\ (Z_i)\ \beta_j \qquad (3.7)$$

Where $\phi(Z_i)$ is the density function associated with each value of the underlying Z_i.

The marginal effect of a dummy variable, say X_1, is computed using the following equation:

$$\frac{\delta\phi\ (Z_i)}{\delta x_i} = (\alpha + \beta_1 + \ldots + \beta_n X_n) - (\alpha + \ldots + \beta_n X_n) \qquad (3.8)$$

Determinants of adoption of virus-tolerant tomato seeds: We hypothesize that the latent variable Z_i depends on farm characteristics such as the producer's experience with yield losses caused by viruses, the effectiveness of current pesticides, the education, and the gender; on farm characteristics such as the proportion of tomato income in the total farm income; and on institutional characteristics such as the actual pesticide and seed costs. We also include some interaction terms to explain gender differences in the adoption of improved seeds. Interactions terms include the experience in tomato losses between men and women (lossexp*gender) and the difference in pesticide costs between men and women (pestcost*gender).

Determinants of adoption of the host-free period: Adoption of the host-free period is assumed to be also a function of farm and household characteristics (gender, education, number of working persons in the household,), farm characteristics (tomato area, distance of the farm to the extension office), and on institution characteristics (contact with the extension agent, membership, and participation in farmer's field school for IPM). The dependent variable representing the host free period adoption is a binary variable which takes on the value one when the producer uses the strategy and zero otherwise. The explanatory variables hypothesized to influence a producer's decision to adopt are summarized in table 3.1.

Endogeneity in host-free period adoption model

The producers' decision to adopt the host-free period strategy may be dependent on their participation in farmer field school training for IPM. Participation in farmer field school training exposes producers to the use of the host-free period strategy for the virus control. Producers who participated in the training may have certain unobserved attributes that are not necessarily correlated with the adoption of the host-free period strategy. These unobserved attributes of the participation in training variable may be correlated with the error term of the adoption variable, which makes the adoption variable endogenous. With endogeneity, the parameter estimates will be biased and inconsistent. To correct the endogeneity in the adoption model, we defined instrumental variables that are correlated with the participation variable but not with adoption of host-free period.

Selection bias in host-free period adoption model

A sample selection bias refers to problems where the dependent variable which measures adoption of host-free period is observed only for a restricted non-random sample. The surveys were conducted in the region of Koulikoro including Baguineda and Kati, the two major zones of tomato production in Mali, and also where the population of the whiteflies, the virus vector, is the highest. However, only producers in Baguineda participated in the farmer field school training and were exposed to the host-free period strategy by the time of our surveys. Producers in Kati were not trained on farmer field school for IPM and were not exposed to the host-free period strategy. The dependent variable (host-free period adoption) was therefore not observed for the sub-sample of producers from Kati. These producers constitute a self-selected sample and not a random sample in our overall sample. Consequently, there is a potential sample selection bias when assessing the adoption using a standard probit model for the whole sample. To address the selection-bias issue, the Heckman probit model is used. Thar model provides consistent, asymptotically efficient estimates for all parameters in our model. Heckman (1978, 1979) suggests a simple method to control for sample selection biases that arise from the existence of unobservable variables. The model consists of a system of two equations. The first equation refers to a self-select equation where the dependent variable is a participation variable, which takes on the value "1" for producers who have participated in the training and "0" otherwise. The latent variable of the selection equation is specified as follows:

$$S_i = \tau c_i + \mu_i \qquad 3.9$$

Where $S_i^* = \begin{cases} 1 & if\, S_i > 0 \\ 0 & if\, S_i \leq 0 \end{cases}$

and $\mu_i \sim N(0,1)$

- S_i = latent variable of the participation in training,

- S_i^* = expected value of the latent variable and, $\Phi(S_i^*) = P(y_{ffs} = 1 | c)$
- c_i = vector of determinants of participation in FFS for the i[th] producer;
- τ = vector of parameter estimates, and
- μ_i = error term

The participation equation is estimated using a probit model and the parameter estimates τ is estimated using the probit maximum likelihood method.

The second equation is the response equation or outcome equation which predicts the adoption of the IPM strategy. The specification of the Heckman probit model is presented as follows:

$$P(y_{HFPi} = 1 | S_i^* = 1, X_i) = \Phi(\beta X_i + E(e_i | S_i^* = 1)) = \Phi(\beta X_i + E(e_i | \mu_i > -\tau' C_i)) \quad (3.10)$$

$$\begin{cases} e_i \sim N(0, \sigma) \\ corr\ (\mu_i, e_i) = \rho \end{cases}$$

$$y_{HFP} = \begin{cases} 1 & if\ P(y_i | S_i^* = 1, X_i) > 0 \\ 0 & if\ P(y_i | S_i^* = 1, X_i) \le 0 \end{cases}$$

- y is the adoption variable which takes on the value one "1" for producers who adopted and zero "0" for non-adopters.
- β is a vector of the coefficients or parameter estimates, and X the vector of parameters being estimated.

3.1.3. **Empirical model**

Tomato producers were asked whether or not they use IPM technologies (host-free period technique, and virus-tolerant tomato seed). The adoption model is evaluated for each IPM technology separately. The left hand side variable is a dummy variable which takes on the value 1 if a producer adopts, and zero otherwise. Table 3.1a presents the variables used for the regression models as well as their expected signs. The right hand side variables, hypothesized to influence the adoption of IPM cropping strategies, are presented as follows:

Producer gender (***Gender***) is a dummy variable that takes on the value 1 for male and 0 for female. A positive sign is expected for this variable because men are the ones first exposed to technologies and they may have a higher propensity to adopt.

Age of producer (***Age***) is a continuous variable expressed in years. We assume this variable would be negatively correlated with the adoption. Young producers may be more inclined to adopt new technologies than older producers.

Marital status ***(Status)*** is a dummy variable that takes on 1 if the producer interviewed is married. A positive correlation is expected because married producers may have more resources (land, labor, capital) than single ones.

Education **(*Educ*)** is a categorical dummy variable with four categories including no education, adult literacy (***Adultliteracy***), basic education (***Basiceduc***) and high school education (***Highschool***). No education is chosen as the reference dummy. The educational variables are expected to increase the probability. In addition, we might also expect a higher probability of adoption between farmers who received adult literacy and those who did not.

Working persons in the household ***(Active)***: This variable represents the number of family members who work in the farm.

Experience in loss ***(Lossexp)*** represents the producer's experience in tomato losses caused by virus. The greater the tomato losses due to virus experienced by the producer, the greater the willingness to adopt the strategy.

Effectiveness of pesticides (***Effectiveness***) represents the producer's belief in the effectiveness of pesticides to control the virus.

Distance from the farm to the extension office (***Disextension***): This variable is used as a proxy for the access to information. With respect to their limited resources, extension agents are more likely to inform nearer farmers than the farther ones.

Tomato area (***Area***) is expressed in hectares. Producers with a large tomato area will be more interested in using IPM strategies to control virus action than farmers with smaller area.

Share of tomato revenue in the annual income (***Tomincome***): This variable measures the proportion of tomato revenue in the household total annual income. A higher proportion is hypothesized to positively affect the adoption.

Proportion of tomato area in the total farm size ***(Sharearea)***: This variable measures the importance of tomato production on the farm. A higher share may favor adoption.

Proportion of tomato sold in the market (***Market***): this is a continuous variable which indicates the percent of tomato the producer sold in the market. The propensity of adoption might be greater if a significant proportion of tomato is sold at the market.

Access to credit (***Credit***): This variable measures producers' access to crop financing. As tomato production is a high value crop, its production requires intensive use of inputs (fertilizer, chemical, labor). Producers who have access to credit would be more inclined to use the new strategies compared to those with limited financing.

Cost of tomato seed ***(Seedcost)*:** This variable refers to the amount of money a producer spent on tomato seeds in general. The variable is used to evaluate the effect on farmer's willingness to adopt a virus-tolerant tomato variety. The adoption of virus-tolerant seeds may decrease when the total amount of money the producer will spend on the virus-tolerant seeds is higher than the amount of money he currently spends on tomato seeds. That is, a negative sign of the coefficient of this variable indicates that producers are not willing to adopt the virus-tolerant seeds. A positive sign indicates that the amount of money the producer actually spends on seeds is higher than the amount of money he will spend on the virus-tolerant seeds. The adoption may occur in this case.

Pesticide cost *(**Pestcost**)* is the total amount of money spent on pesticides during the production. The adoption of virus-tolerant varieties is an effective substitute for pesticides. The higher the current expenditure on pesticide is, the higher the propensity of using alternative technologies which requires lower pesticides usage.

Previous training in insects and diseases control *(**FFSipm**)*: This variable indicates whether or not the producer has participated in farmers' field school for IPM. We hypothesize that previous training in IPM techniques would positively affect the adoption of the technologies. As explained in previous section, the farmer's field school for IPM variable is a source of endogeneity in the model because producers who attended this training were not selected randomly. Instead, they were selected by the extension agents based on certain specific characteristics unknown for us. We assume that such characteristics may include the educational level, gender, membership, and the frequency of extension agents visits.

Contact with extension ***(Contact)***: This variable measures the frequency of visits by the local extension agent. A higher frequency of visits will favor the adoption of the technologies, while a lower frequency is expected to lower the propensity of adoption.

Membership in community organization (***Membership):*** A community organization is a place where information is released and diffused; it measures the level of farmer's exposure to information. We assume that the membership of farmers in community organization may influence positively the adoption of IPM technologies.

Table 3.1a: Names and description of adoption variables

Variable name	Variable description	Modalities
Household's Characteristics		
Gender	Gender of the producer	1. Male 0. Female;
Age	Age of the producer in years	In years
Status	Marital status of the producer	1. Married; 0. Otherwise
Basiceduc	Whether the producer completes primary school *(no education as a baseline group)*	1.Basic education; 0. Otherwise
Highschool	Whether the producer attended high school for some years	1. High school; 0. Otherwise
Adultliteracy	Whether the producer can read or write in the local language	1. Adult literacy; 0. Otherwise
Active	Number of working persons in the household	Numbers
Lossexp	Producer's experience in tomato losses caused by virus	Years
Effectiveness	Producer belief of pesticide effectiveness on virus control	1. If he believes 0. Otherwise
Farm characteristics		
Disextension	Distance from the farm to the nearest extension agent office	In km
Area	Tomato area	Hectares
Tomincome	% of tomato income in annual farm income	%
Sharearea	Share of tomato area in the total farm size	%
Institutions		
Market	Proportion of tomato sold in the main market	%
Credit	Producer access to crop financing	Currency
Seedcost	Cost of tomato seed	Currency
Pestcost	Expenditure on pesticides	Currency
Ffsipm	Producer's training in pest and disease control	1. if producer received a training 0. Otherwise
Contact	Contact with extension agent	1. if extension agent visited the producer 0. Otherwise
Membership	Membership of the producer in the community organization	1. if producer belongs to the organization 0. Otherwise

3.1.4. **Sampling and Data**

A baseline survey was conducted in Mali and Senegal in 2006. Additional surveys were conducted in June-July 2009. Two different types of villages were selected: IPM villages where IPM strategies were implemented or diffused through farmer's field school (FFS) and non-IPM villages where the IPM program was not implemented, nor was the diffusion observed at the time of our surveys. The non-IPM villages were selected as a basis for comparison in order to evaluate changes, if any, that the implementation of the strategies might have on households' production and income. Producers from IPM villages were exposed to the technologies through field trials and through technical support from local research and extension agents including FFS training or visit-based advice on appropriate use of the technologies. In each country, a total of 150 households were randomly selected in each IPM and non-IPM village, or 300 per country. Tables 3.1b & 3.1c show villages where the surveys were conducted and the number of households surveyed.

Table 3.1b: Location of the surveys and sampling in Mali

Districts	Districts	Female	Male	Total
Baguineda-Camp	Baguineda-Camp	73	77	150
Kati	Kalifabougou	24	25	49
	Diago	17	17	34
	Dio-gare	15	16	31
	Yelekebougou	17	19	36
	Total	146	154	300

Source: Sampling data of Mali *(See map in Annex for details)*

Table 3.1c: Location of the surveys and sampling in Senegal

Regions	Districts	Female	Male	Total
Dakar	Sangalkam	4	35	39
	Yenne	3	31	34
Thies	Tivaouane	6	24	30
	Notto G Diame	5	18	23
	Darou khoudoss	18	8	26
Louga	Kebemer	11	15	26
	Louga	18	21	39
Saint Louis	Dagana	3	66	69
Total		68	218	286

Source: Sampling data of Senegal *(See map in Annex for details)*

Data were collected through direct interviews with producers, extension agents and scientists from both countries. Producers were asked to give their perceptions, awareness and knowledge of virus problems, constraints to adoption of IPM strategies, tomato varieties, reasons for growing those varieties, and the source of tomato seeds. Producers were also interviewed on the source of information of the cropping strategy they are using, and whether or not they received any training associated with IPM technologies. Production related information includes tomato acreage, the cost incurred for the production such as seed, labor, chemicals (fertilizer and insecticides), and other operational costs associated with the production such as marketing costs. Market related data include the proportion of tomato sold, period when tomatoes are sold the most, as well as tomato prices across markets and over time.

3.2. Economic impact of the adoption of IPM strategies

The economic impacts of IPM strategies are assessed at both the individual level and societal level. The individual level economic impact includes the use of budgets to analyze changes in costs of production or profitability, whereas the societal impact analysis focuses on the changes in economic welfare of producers and consumers resulting from the market-level changes in prices and supply (Norton *et al.* 2005).

3.2.1. **Economic impact of IPM strategies adoption at individual level**

A partial budget is developed for each of the technologies implemented including the host-free period and improved tomato varieties. The partial budget analysis uses the benefits and costs components which are supposed to vary significantly as a result of the adoption of the new technique or strategy. We rely on such an approach for the individual level assessment because it is the most commonly used method for assessing IPM impacts (Norton *et al.* 2005. op. cit.). Data used for the analysis come from direct interviews (surveys) with tomato producers, both adopters and non-adopters of IPM strategies, using a formal questionnaire. Producers who adopted the strategies are asked about the yield obtained from tomato production, the production cost incurred as well as the selling price of tomatoes at the time they sold most of their tomatoes. The minimum and the maximum prices are also recorded to show the range of the gross margin. Data on inputs costs such as seeds, fertilizers, insecticides, and labor are obtained from the extension office at the location where the technologies are implemented. The gain from the adoption is first evaluated per hectare, and then evaluated at a household level using the average tomato area per household. The rate of return for each technology is estimated using the total revenue obtained from the production over the total production cost. In addition, calculations are made of the total gain, given the number of tomato producers in the location where the strategies are implemented, and the adoption rate computed through data collected from scientists during the baseline surveys in the country in July-September 2006. Calculations are also made to evaluate the potential gain for the region over time after estimating the year in which the maximum adoption is reached. We assume the current technologies will become obsolete and tomato producers will attempt to seek alternatives by 2020. The potential gains are discounted and the net present value (NPV) is estimated. For Senegal, calculations are not performed because of lack of baseline data for the prediction.

The benefits of a host-free period are evaluated by comparing the partial budget of the virus-sensitive variety "Roma" before and after the implementation of the strategy. The variety Roma is chosen because of its sensitivity to viruses and its accessibility to producers. The difference in yield of Roma before and after the implementation of the host-free period is used as a proxy for the effect of the strategy on tomato production. The benefits of the host-free period are expressed in terms of cost-savings for insecticides, and change in yield. Analytically, these benefits can be explained through the following equations:

$$Benefit = (\Delta Q \times P) - (\Delta C) \tag{3.11}$$

Where:

- P is the price at which the producer sells his tomato
- Q is the quantity of tomato produced per hectare, and
- C is the per hectare production cost
- ΔQ is the change in production ($\Delta Q = Q_{\text{under hfp}} - Q_{\text{without hfp}}$)
- ΔC is the change in insecticide cost ($\Delta C = C_{\text{under hfp}} - C_{\text{without hfp}}$)

Likewise, the benefits resulting from using virus-tolerant or resistant tomato varieties are evaluated by comparing the partial budget for both virus-sensitive and tolerant varieties. These benefits are expressed in terms of a yield differential, and changes in production cost. The difference between the cost of virus-sensitive seeds and virus-tolerant ones is perceived as a technology fee. This fee is expressed as a proportionate change in cost with respect to the virus-sensitive tomato seed. The rate of return (RoR) is calculated for both adopters and non-adopters of the strategies. The change in the rate of return is estimated in order to appreciate the effect of adoption. The rate of return is calculated using the following equation:

$$RoR = \frac{\text{Revenue} - \text{cost}}{Cost} x100 \qquad (3.12)$$

3.2.2. **Economic impact of IPM strategies adoption at societal level**

At the societal level, the economic impact of IPM is assessed using the economic surplus approach. The economic surplus approach combines cost, yield, and price changes with adoption estimates, the change in supply and demand as a result of the new strategy. Both closed and open economy assumptions are explored in this study for each of the IPM technologies including the cropping practices (host-free period) and the development of tolerant varieties. The next section describes the basic approach that outlines the theoretical framework.

3.2.2.1. **Basic approach of economy surplus approach**

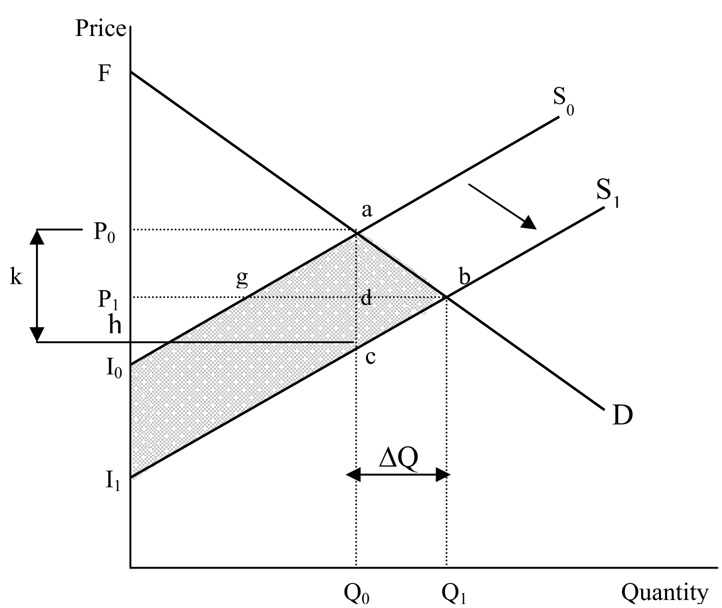
Closed-economy assumption

When widespread adoption of IPM technologies across large areas occurs, changes in crop prices, cropping patterns, producer profits, and overall societal welfare can occur and economic surplus analysis captures these changes. The changes arise because costs change and because supplies may increase, affecting prices for producers and consumers. These changes are illustrated for the closed economy model (figure 3.2a) which shows the research benefits resulting from adoption of an improved tomato seed to reduce virus problems.

Figure 3.2a illustrates a change in supply after a technological change for a single homogeneous good (tomato). In this figure, line D represents the demand curve for the good (tomato), while line S_0 represents the supply curve of the tomato before the adoption of an IPM strategy. The initial equilibrium price and quantity are P_0 and Q_0

respectively. The area of the region FaI_0 represents the total economic surplus before the adoption of IPM strategies and virus-tolerant tomato. This area is made up of the sum of consumer and producer surpluses, represented by the areas FaP_0 and P_0aI_0 respectively. We assume that demand and supply curves are linear, demand for tomato remains unchanged, and that the supply curve shifts parallel to its initial position, as a consequence of technological change. We assume an outward shift in the supply curve to S_1 because we expected that adoption of technologies diminishes the per-unit cost of tomato production. This shift induces an increase in production and consumption of Q_1 (by $\Delta Q = Q_1 - Q_0$); the market price falls to P_1 (by $\Delta P = P_1 - P_0$). The new equilibrium price and quantity are P_1 and Q_1 respectively. The total economic surplus after the adoption of IPM technologies is represented by the area FbI_1 which consists of the sum of the corresponding consumer and producer surpluses, (FbP_1 and P_1bI_1 respectively). The gain in economic surplus is represented by area FbI_1 minus area FaI_0 which yields area I_0abI_1.

Figure 3.2a: Shift of supply curve due to technological change closed-economy



The change in total economic surplus (ΔTS) is also defined as the sum of a change in consumer surplus (ΔCS) and a change in producer surplus (ΔPS). These changes are expressed as follow:

$$\Delta CS = FbP_1 - FaP_0 = P_0abP_1 = P_0agP_1 + abg \quad (3.13)$$

$$\Delta PS = P_1bI_1 - P_0aI_0 = (I_0gbI_1 + P_1gI_0) - (P_0agP_1 + P_1gI_0) = I_0gbI_1 - P_0agP_1 \quad (3.14)$$

$$\Delta TS = (P_0agP_1 + abg) + (I_0gbI_1 - P_0agP_1) = abg + I_0gbI_1 = I_0abI_1 \quad (3.15)$$

Consumers are better off and producers may be better off after the adoption of IPM technologies. Consumers can buy more tomatoes (Q_1) at a lower price (P_1) and benefit by an amount equal to their cost savings on the original quantity ($Q_0 * \Delta P$) plus their net benefits from the increment to consumption. Producers' per-unit production costs have fallen by the amount (k) and they gain additional income from that, although part (or even all) of their gains are offset by the lower price. Based on our assumptions, (linear demand and supply curves, and parallel shift in the supply curve), the changes in consumer surplus, producer surplus, and economic surplus can be computed as follows:

$$\Delta CS = P_0Q_0Z(1 + 0.5Z\eta) \quad (3.16)$$

$$\Delta PS = P_0Q_0(K - Z)(1 + 0.5Z\eta) \quad (3.17)$$

$$\Delta TS = P_0Q_0K(1 + 0.5Z\eta) \quad (3.18)$$

Where

- K = vertical shift of supply curve expressed as a proportion of the initial price;
- η = absolute value of the elasticity of demand,
- ε is the elasticity of supply,

- $Z = \frac{K\varepsilon}{\varepsilon + \eta} = -\frac{(P_1 - P_0)}{P_0}$ is the decrease in tomato price, relative to its initial value, due to the shift in supply. For more detail on the algebraic proof, see footnote below (Alston, Norton, and Pardey 1995, p. 210-211)[1].

The magnitude of the change in producers' and consumers' benefits depends on the price elasticity of demand. Under perfectly elastic demand observed in a perfectly competitive market, consumers' surplus is zero because the price that consumers pay in this situation coincides with the price they are willing to pay for the good. All the benefits resulting from the adoption of the new technologies go to producers.

Open economy assumption:

When the IPM technologies are widespread and tomato viruses controlled, and considering the absence of a cannery to process the oversupply of tomato, producers in Mali will again seek alternatives such as exploring regional markets to absorb this excess supply as it was the case before the apparition of the virus. Yet in the country

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[1] Algebraically, the parameters Z and K were calculated using our assumption of linear supply and demand curves and a parallel shift down of the supply curve, the supply and demand equations can be written as follow: $Q_s = \alpha + \beta(P+k) = (\alpha + \beta k) + \beta P$ and $Q_D = \gamma - \delta P$
The shift down of the supply curve relative to the initial equilibrium is given by $K=k/P_0$. The equilibrium price obtained by solving $Q_s=Q_D$ is $P= (\gamma - \alpha - \beta k)/(\beta + \delta)$

Before the shift of the supply curve, k =0, and $P=P_0$; after the parallel shift, $k=KP_0$
and $P=P_1$. The absolute value of the change in price relative to the initial equilibrium resulting from the research - $(P_1-P_0)/P_0$ is obtained by solving the following system of equations.

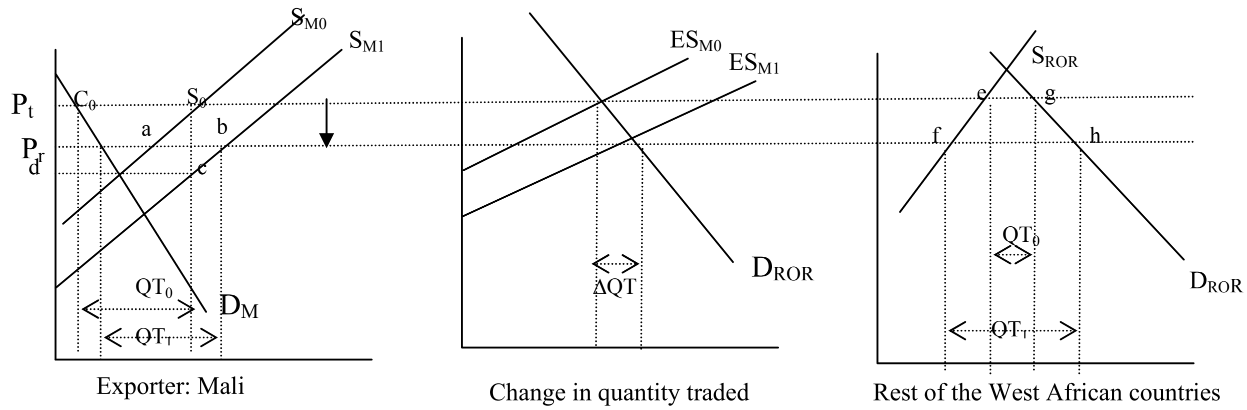
$$\begin{cases} P_0 = (\gamma - \alpha)/(\beta + \delta) \\ P_1 = (\gamma - \alpha - \beta K P_0)/(\beta + \delta) \end{cases}$$

Solving this system of equations yield to $-(P_1-P_0)/P_0 = \beta K/(\beta+\delta)$
Using the supply and demand equations above, the slopes β and δ are given by:
$\beta = \Delta Q_s/\Delta P$, and $\delta = \Delta Q_D/\Delta P$. By multiplying β and δ by P_0/Q_0 leads to elasticities of supply and demand (ε, η). That is, $\beta K/(\beta+\delta) = K\varepsilon/(\varepsilon+\eta) = Z$
Consumer surplus algebra:
$\Delta CS = P_0abP_1 = P_0adP_1 + abd = Q_0(P_0-P_1) + 0.5(Q_1-Q_0)(P_0-P_1) = Q_0(P_0-P_1) + 0.5Q_0(Q_1-Q_0)(P_0-P_1)/Q_0 = Q_0(P_0-P_1)[1+0.5(Q_1-Q_0)/Q_0] = Q_0(P_0-P_1)[1+0.5Z\eta] = Q_0P_0Z)[1+0.5Z\eta]$
Producer surplus algebra:
$\Delta PS = I_0gbI_1 - P_0agP_1 = P_1dch + bcd = (P_1-h)Q_0 + 0.5(P_1-h)(Q_1-Q_0) = (P_1-h)Q_0[1+0.5(Q_1-Q_0)/Q_0]$; $(P_1-h) = (P_1-P_0)+(P_0-h) = (P_0-h)-(P_0-P_1) = KP_0-P_0Z$
$\Delta PS = (KP_0-P_0Z)Q_0[1+0.5Z\eta] = (K-Z)P_0Q_0[1+0.5Z\eta]$

there is a new processing unit (SOCAM) which is in its implementing phase but still waiting for approval from the government. The objective of this cannery is to absorb the oversupply of tomatoes at any moment by the time the strategies to control viruses are fully adopted, and then the country will become a net exporter of tomatoes in the region.

We propose a large open economy model given our assumption that Mali is a large exporter country for fresh tomatoes in West Africa. The open economy model is considered as an alternative to absorb the oversupply of tomatoes in case the new SOCAM cannery does not get its project approved. Under open economy assumption, we assume that in the near future, producers may independently seek alternatives by trading their tomatoes within the West African countries. The large open economy assumption is graphically illustrated in figure 3.2b. Our illustration is based on the case presented by Alston et *al*. (1995, p 214). In this figure, we assume that Mali is a large net exporter of fresh tomatoes in West Africa. The domestic level of supply and consumption is represented by C_0 and S_0, the intersection between the price P_t and the domestic demand (D_M) and supply curves (S_{M0}) respectively. The quantity initially traded is indicated by QT_0 and the excess supply is represented by ES_{M0}. The regional demand curve for fresh tomatoes, that is, the aggregate demand of the rest of West African countries, is represented by D_{ROR}. The implementation of IPM technologies increases the domestic supply for fresh tomatoes, which shifts from S_{M0} to S_{M1}; the domestic demand is assumed to be constant after the shift. The excess supply shifts from ES_{M0} to ES_{M1} affecting therefore the regional market price, which decreases from P_t to P_r. The quantity traded increases to QT_1 and the difference between QT_1 and QT_0 (or ΔQT) is the positive change in trade volume induced by the research (IPM program) in the region. Producers in Mali are better-off as they can trade the excess supply to the rest of the region (ROR). Producers in the ROR are worse-off especially in the period where the tomatoes from Mali overflow to the region, and may be as well-off in the period the volume of trade is negligible to influence the regional price. Consumers in Mali as well as in the ROR are also better-off because of the reduction of tomato price. The benefits of producers in Mali are represented by $P_r$abcd while the benefits for consumers are $P_t$caP_1. In the ROR, the loss of producers is represented by $P_t$efP_r, whereas the benefits for consumers are represented by $P_t$ghP_r.

Figure 3.2b: Shift of supply curve due to technological change for an open-economy



Under a small open economy assumption the research benefits from a *K* percent parallel shift down in the supply curve is given by:

$$\Delta TS = K_t P_t Q_t (1 + 0.5 K_t \varepsilon) \qquad (3.19)$$

Where:

- P_t is the initial price (pre-research price), and
- Q_t is the initial quantity in year t after accounting for exogenous shift effects.

It is assumed that the subject country (Mali), does not affect the international price of tomatoes, and therefore the world price is constant at P_t, and all benefits are reflected as an increase in producer surplus after the shift in the supply curve.

As indicated in our model prediction, the annual demand for fresh tomato averages 68,703 tons in Mali. This quantity can be reached in the near future as adoption has been growing recently. Using the potential yield of 40t/ha obtainable from the virus-tolerant variety H8804, and assuming that the adoption is spreading in the near future given the strong support of the IICEM/USAID-Mali project, the potential level of production in the country would be roughly estimated at 152,700 tons per year (cf. table 3.2.a).

Table 3.2a: Tomato area under cultivation and the potential level of production

	Area (ha)	Potential production * (Yield = 40 t/ha)
Bamako	150	6000
Koulikoro (Baguineda, Kati)	1404	56160
Ségou	1488	59520
Sikasso	378	15120
Kayes	78.5	3140
Mopti	178	7120
Tombouctou	100	4000
Gao	34	1360
Kidal	7	280
Total	**3817.5**	**152700**

Source: Mali Agriculture website, 2009

*: The potential yield is estimated using the expected yield of H8804 which is about 40MT/ha

3.2.2.2. **Discount factors**

The benefits of the adoption of the IPM strategies may erode over time because of depreciation and obsolescence. Depreciation occurs because circumstances and the environment in which these technologies were implemented change, which make the technology less productive (Altson et *al. op cit*, p31). This often happens when research benefits are explicitly measured as changes in economic surplus for both consumer and producer. In our study, the benefits generated by the adoption of a host-free period and virus-tolerant tomato seeds therefore need to be discounted. The net present value (NPV) of discounted benefits and costs can be calculated using the following equation:

$$NPV = \sum_{t=1}^{T} \frac{R_t - C_t}{(1+i)^t} \qquad (3.20)$$

Where: R_t = the return in year *t,* C_t = the cost in year t, i= the discount rate

Most countries in West Africa use a discount rate of 4.25% when valuing public investment. Recently, the central bank of West Africa States (BCEAO) has raised the discount rate from 4.25 to 6.75 (African Economic Outlook, 2008). For this study, the discount rate chosen is 5%.

The internal rate of return (IRR) is the interest rate (or discount rate), *i*, at which NPV equals zero. It represents the average earning power of the money used in a project over its whole life. It is obtained by solving the following equation, on an iterative basis:

$$\sum_{t=1}^{T} \frac{R_t - C_t}{(1+i)^t} = 0 \qquad (3.21)$$

The benefit-cost ratio (BCR) is also used in this study to decide whether or not to promote virus-tolerant tomato varieties on a large scale. Mathematically, BCR is calculated using the following equation:

$$BCR = \frac{\sum_{t=0}^{T} B_t / (1+i)^t}{\sum_{t=0}^{T} C_t / (1+i)^t} \quad (3.22)$$

If BCR > 1, then NPV > 0 and project is acceptable

3.2.2.3. **Model predictions**

The benefits resulting from the adoption of the IPM-technologies are estimated for an 18-year period from 2003 to 2020, although benefits are zero for the first five years of adoption of improved varieties. The predictions are made for both closed and open economies. A closed economy market is the domestic market in which the price of tomato is determined by the domestic supply and demand for tomato. In the open economy market, the price of the good is determined in the international market, and therefore it is not affected by the local supply. The demand of the good is in this case infinitely elastic and all the benefits go to producers. For both closed and open economy markets, the research benefits are estimated for IPM crop practices (host-free period) and for tomato virus-tolerant varieties. The net present value (NPV) of net benefits over the time period is projected for each technology; the internal rate of return (IRR) is also estimated. The value of the IRR is an indicator of whether it is suitable or not to continue investing in these technologies.

3.2.2.4. **Data requirements and indicators estimates**

* *Sources of data:* Two types of data were collected for the analysis: primary data and secondary data. Primary data were collected from tomato producers, scientists, and consumers to assess supply and demand of tomato. The evaluation of potential adoption of the technologies was obtained from local scientists. Secondary data were obtained from various sources including reports from previous programs on tomato in Mali, the

National statistical office in Mali, and from the database of the Food and Agriculture Organization of the (FAOSTAT).

* *Price of tomato:* The time series of domestic market prices of tomato were obtained from the research and extension offices in Mali and Senegal during the period of investigation. Using the same sources, the average price of tomato was estimated at $220 per ton, ranging from $170 to $250 per ton.

* *Quantity of tomato supplied:* The quantity supplied varies over years. Quantity data came from a USAID report published in 2007, the FAOSTAT website, the UN COMTRADE (2009), and the International Chamber of Commerce (see table 3.2b). The average annual quantity of 68,703 tons used for our simulation is obtained by computing the average total production of 2004-2006.

Table 3.2b: Trends in quantity of tomato produced in Mali

Year	Production (tons)	Import (tons)	Export (Kg)	Re-Export (Kg)	Total quantity (tons)
2001	55000	0.3	-	-	55000
2002	55000	-	-	-	55000
2003	60610	2.3	-	-	60612
2004	66792	7.6	-	-	66800
2005	64000	22.7	-	-	64023
2006	75316	380.3	-	-	75696

Source: USAID-Mali (2007); FAOSTAT, ICC (2006), UN Comtrade Database (2009)

* *Demand and Supply Elasticities:* Domestic demand and supply elasticities were obtained through published reports. In our study, we assumed that the elasticity of supply is 1.0. The tomato is a normal good in West Africa and the price elasticity of demand is similar in size to the income elasticity (but a little larger). For this study we assumed that the price elasticity of demand for tomato (η) may be close to -0.50.

* *Expected yield change:* The expected change in yield due to adoption of IPM strategies is estimated based on direct interviews with scientists involved in developing tomato technologies in Mali in 2006. The expected proportionate yield change per hectare E(Y) when the whitefly management program is developed and a variety is eventually developed to resist viruses is E(Y) = 0.63. A sensitivity analysis is conducted for the overall IPM program by gradually decreasing this value in order to see the change in research benefits (cf. Table 3.2.9). The percentage contribution to yield change induced by the IPM cropping strategies and virus-tolerant varieties technology development are also obtained. The values of that contribution are 0.52 [or 0.63*(0.24+0.14+0.32+0.13)] for the host-free period, and 0.11 (or 0.63*0.17) for virus-tolerant varieties development. Data used to estimate the change in yield are indicated in table 3.2.c.

Table 3.2.c: Expected proportionate yield change from research components

Contribution of each research component to the expected yield change				
Whitefly management system	Survey of virus diseases	Screening of varieties for virus resistance	Development of diagnostic tools for national labs	Development of resistant variety
24%	14%	32%	13%	17%

* *Proportionate change in input cost per hectare:* The proportionate change in input cost per hectare to achieve the expected yield change is computed using data provided by activity reports on the percent change in cost per hectare for tomato production inputs and the share (percent) of the total variable costs in tomato production devoted to each input used. Tables 3.2d & 3.2e provide information on the estimate of the percent change in cost for each of the tomato production inputs if the tomato virus technologies above were developed, and the proportions of variable costs in tomato production. The proportionate change in input cost per hectare to achieve the expected yield change for

improved seeds is E(C) = 0.02 [(∑ (% of cost change per ha x % of the variable cost)], and for the host-free period, E(C) = 0.04 (see tables 3.2 d & e).

Table 3.2d: Proportionate change in input cost due to adoption of improved seeds

	Labor	Seed	Fertilizer	Fungicide	Insecticide	Others
% of cost change per ha	-1%	14%	4%	26%	-11%	-
% of variable cost	31%	13%	33%	-	9%	13%
E(C) = 0.02						

Table 3.4e: Proportionate change in input cost due to adoption of host-free period

	Labor	Seed	Fertilizer	Fungicide	Insecticide	Others
% of cost change per ha	-1%	14%	4%	26%	**-71%**	-
% of variable cost	31%	13%	33%	-	9%	13%
E(C) = 0.04						

* *Adoption rate:* The adoption rate of IPM practices is estimated based on data collected from scientists in Mali. Scientists are asked about the percent of farmers they believe would adopt the virus-tolerant variety that meets the required quality characteristics. They are also asked about the number of years that would pass before adoption would be at a maximum. For our calculation we assume that the adoption rate occurs in a linear fashion, and that the maximum adoption can be obtained five years after the technology is introduced. The yearly adoption rate is calculated by dividing the average projected maximum percent of adoption by the average of years. In the case of the host-free period in the project area, a total adoption is possible given the existence of the enforcement policy to comply with the strategy. We conduct a sensitivity analysis using different rates of maximum adoption of 15%, 30%, 45%, 60%, and 100%. At the country level, a maximum adoption rate of 60% is assumed, given the fact that the enforcement policy at the country level may not be effective enough for total compliance. Sensitivity analyses are conducted using different rates of maximum adoption of 15%, 30%, 45%, and 60%.

* *Probability of Research success:* The probability of research success is the probability of achieving 100% of the yield change. Using data provided by scientists, the probability of research success was estimated for each component of the technology. Table 3.2f presents the results obtained from our calculation. On average, the probability of successful development of IPM technologies is p = 0.45. We conducted a sensitivity analysis by decreasing this probability gradually to see the change in the research benefits (cf. table 3.2g).

Table 3.2f: Probability of Research success on tomato in Mali

Research components	Probability of success
White fly management system	0.35
Survey of virus diseases	0.47
Screening of varieties for virus resistance	0.56
Development of diagnostic tools for national labs	0.41
Development of tolerant varieties	0.48
Average	***0.45***

* *Research Cost:* The annual research cost for the development of technologies includes technology development and regulatory costs. The regulatory cost is due to the cost of obtaining research approval, confined and multi-location field trials, bio-safety assessments, and approval for commercialization. Using data from scientists and from the IPM program staff, the research cost corresponding to expected yield increases was projected to be $100,000 annually and to be constant for 10 years after the research commences. For the development of virus-tolerant varieties, we assume that this annual research cost is reduced by half (or $50,000). For the host-free period strategy, we used the training cost for the next phase of IPM in the region, which is estimated to be $180,000 for three years. This amount includes both the host-free period and the pesticide safety training cost. We assume the host-free period training cost represents

half of the total training cost. The annual host-free period training cost is then estimated at $30,000 and assumed to be constant over time.

** Parameter values for the computation of economic surplus changes:* A spreadsheet approach is used to compute the research benefits. Two market assumptions are used for computation of research benefits: a closed economy and an open economy. For each assumption, three scenarios are considered:

- *Scenario 1: IPM strategies (host-free period)*
- *Scenario 2: Development of improved varieties*
- *Scenario 3: Overall IPM program (IPM strategies and improved varieties)*

The major assumptions and values of indicators are summarized in table 3.2g.

Table 3.2g: Summary of the main assumptions

	Majors assumptions used for calculations			
	Host-free period adoption in Baguineda	**Host-free period adoption for the whole country**	**Improved variety**	**Overall IPM program (HFP + improved variety)**
Elasticity of supply (e)	1.00	1.00	1.00	1.00
Elasticity of demand (n) *In absolute value*	0.50	0.50	0.50	0.50
Yield change	1: Our results showed that the change in yield after HFP strategy was implemented was about 425%. For the calculation, we assume a 100% increase in yield as an average yield change across the zone.	0.52: The expected proportionate yield change from IPM strategy is estimated based on data provided by scientists in Mali.	0.11: The expected proportionate yield change from improved variety development is estimated based on data provided by scientists in Mali.	0.63: We use the likely expected proportionate yield change per hectare given by scientists assuming that all the IPM components are developed. Sensitivity analysis is conducted by decreasing gradually this value.
Probability of Success	1: The HFP strategy is a success. Both scientists and producers are convinced about its effectiveness in controlling whiteflies, the virus vector. We assume the success is total and that the probability of success is 1.	0.45: We use the value given by scientists for the successful development of IPM program.	0.44: We use the value obtained from scientists in the country.	0.45: we use the value given by scientists for a successful development of IPM program in the country. Sensitivity analysis is conducted by decreasing gradually this value.

Table 3.2g Summary of the main assumptions (continued)

	Host-free period adoption in Baguineda	Host-free period adoption for the whole country	Improved variety	Overall IPM program (HFP + Improved Variety)
Proportionate change in input cost per hectare	E(C) = 0.04 (calculated using data from scientists in the country).	E(C) = 0.04 (calculated using data from scientists in the country).	E(C) = 0.02 (calculated using data from scientists in the country).	E(C) = 0.06 (sum of E(C) of HFP and improved varieties.
Adoption Rate *(Maximum adoption occurs 5 years after the technology commences)*	We assumed a total adoption can be reached for HFP given the enforcement policy in the location. Sensitivity analyses are conducted by varying the maximum rate of adoption from 15% to 60% with an increase of 15%. Because the adoption can be maximal in the location, a sensitivity analysis using 100% of adoption rate is also conducted.	For the whole country, a maximum adoption rate of 60% is used. Sensitivity analyses are conducted by varying the maximum rate from 15% to 60% with an increase of 15%.	For the whole country, a maximum adoption rate of 60% is used. Sensitivity analyses are conducted by varying the maximum rate from 15% to 60% with an increase of 15%.	For the whole country, a maximum adoption rate of 60% is used. Sensitivity analyses are conducted by varying the maximum rate from 15% to 60% with an increase of 15%.
Depreciation Rate	0: We assume the depreciation rate equals zero.	0: We assume the depreciation rate equals zero.	0: We assume the depreciation rate equals zero.	0: We assume the depreciation rate equals zero.
Quantity	The level of tomato production reported for the year 2008 in the location is 2800 tons. This quantity is used for the prediction.	At country level, we estimate the production based on the quantity calculated for Baguineda. (2800*3817.5/95*2)≈ 56,260 tons.	The quantity is estimated using the average of 2004, 2005, and 2006 (table 3.2b). This quantity is estimated to be about 68,703 tons per year.	The quantity is estimated using the average of 2004, 2005, and 2006 (table 3.2b). This quantity is estimated to be about 68703 tons per year.

Table 3.2g Summary of the main assumptions (continued)

	Host-free period adoption in Baguineda	Host-free period adoption for the whole country	Improved variety	Overall IPM program (HFP + Improved Variety)
Exogenous output change	0.01	0.01	0.01	0.01
Price of tomato	$220/MT	$220/MT	$220/MT	$220/MT
Research cost	30,000* 1404/2892) = 14,564 ≈ 15,000	30,000*3817.5/2892= 39,600≈ 40,000	50,000	90,000
Discount rate	5%	5%	5%	5%
Closed economy assumption	- Demand and supply curves are linear - Parallel outward shift of supply curve as a result of reduction of production cost after adopting the technologies - Demand for tomato is assumed to be constant for the country			
Open economy assumption	-The excess demand for the rest of the region is horizontal as Mali is a small country - Parallel outward shift of supply curve as a result of reduction of production cost after adopting the technologies			

4. Results

4.1. Tomato yellow leaf curl virus control methods in West Africa

4.1.1. Adoption of host-free period and net-protected nursery

Before the TYLCV became widespread, Mali was a net exporter of tomatoes in West Africa. The production generated significant revenue and represented one of the major sources of income for rural households. Tomato revenue has been reduced significantly since the virus became widespread. Tomato production in Mali generally occurs twice a year: June to September and December to March. Because of the increased pressure of whiteflies (the vector of the virus) in June and July, tomato production was not possible during the first period of production. The implementation of the host-free period avoids tomato production in June and in July, period over which the population of whiteflies is high. Noussourou (2007) showed that the population of whiteflies dropped significantly when producers delayed tomato production from June to August, because whiteflies can live up to thirty days, and the virus cannot be transmitted from one generation to another. That is, the new generation of whiteflies does not carry the virus unless they feed on infected plants.

As reported by producers, the host-free period strategy was successful in controlling whiteflies incidence on tomato. Our data reveal that 84% of producers have adopted the host-free period in Mali. Among them, 76% report that the strategy is effective in controlling the whiteflies incidence on tomato. The systematic phytosanitary clearing of tomato field recommended to producers just after harvesting tomatoes contributes the effectiveness of the host-free period. The phytosanitary clearing consists of destroying all tomato plants in the farm after harvesting tomatoes in order to break the virus life cycle and prevent the infestation of the new generation of whiteflies from old tomato plants.

In Senegal, the net-protected nursery was introduced as a strategy to control whitefly-transmitted viruses on tomato. As opposed to the host-free period strategy, the net-protected nursery consists of avoiding the physical contact of whiteflies in the early development stage of the tomato plants given that when the virus infestation is delayed; its impact on production is not significant. However, this strategy was not successful as its adoption was not widespread. Our data indicate that only nine percent of the sampled producers were trained on the use of the net and six percent have continued to use the strategy.

4.1.2. **Adoption of virus-tolerant or resistant tomato seeds**

The most common tomato varieties grown in Mali are the virus-tolerant Shasta and H8804, and the virus-sensitive Roma. The virus-sensitive tomato variety Roma-VF is the most produced and it is grown by 70% of the sampled respondents whereas the virus-tolerant Shasta and H8804 are grown by 18% and 12% of the producers respectively. With respect to the IPM villages, these proportions represent 40% for Roma-VF, 36% for Shasta, and 24% for H8804 (cf. table 4.1a).

The average yields of Shasta and H8804 obtained at farm level are approximately 16 and 12 tons per hectare respectively. However, a potential yield of more than 60 and 30 tons per hectare can be reached for Shasta and H8804 respectively in this location (IICEM/USAID, 2009). The difference between the yield obtained in the farm and the potential yield may be partially explained by some constraints associated with the production of these varieties, in particular the cropping patterns and the relatively high cost of virus-tolerant seeds. Improved varieties are often fertilizer-responsive and sometimes labor-demanding. Due to capital constraints, most producers may not be able to afford the required amount of fertilizer to reach the potential yield. They also may not be able to devote the appropriate amount of labor because of the allocation of the limited number of working persons for other crops. More importantly, the seeds of the virus-tolerant varieties Shasta and H8804 cost almost $19 and $33 per 10 grams respectively (IICEM/USAID, 2009). This amount represents almost ten to thirty times the cost of the same quantity of the virus-sensitive seeds. The low yield recorded by producers may be due to the low density of plants because of the relatively high cost, or to the non-compliance of the cropping pattern because of the limited amount of labor in the household. However, the distribution of yield around the average is large for Shasta (SDV=14 t/ha), while H8804 presents a low yield variability (SDV=6t/ha) indicating that some producers record a relatively high yield using the virus-tolerant seeds.

The average yield of the virus-sensitive variety Roma is about 18t/ha in the program area, which is similar to the yield obtained under experiments (17.15t/ha), but the variation remains high meaning that the range of yield across producers is large. Such a level of yield obtained for the virus-sensitive variety is explained by the use of the host-free period strategy which reduces the incidence of whitefly and of the virus. Conversely, the maximum yield attainable for Roma in areas where the host-free period is not held averages only 3t/ha. Assuming that the production systems in both areas are similar, the difference in yield can be ascribed to the use of the host-free period strategy.

In Senegal, the most common tomato varieties grown across the country are the virus-tolerant varieties, Gempride and Mongal $F_{1;}$ and a virus-sensitive variety, Kher. The proportion of producers using virus-tolerant varieties across the study area is 70% (24% for Gempride and 46% for Mongal) compared to 30% for the virus-sensitive one. The virus-tolerant Gempride is mostly grown in Saint-Louis because of the tomato cannery, whereas Mongal is commonly produced in Thies, Dakar, and Louga.

Tomato production systems are diversified across the country with different levels of productivity. Dakar and Thies are favorable for tomato production because of the high rainfall while Louga and Saint Louis are characterized as dry areas with a low level of humidity. The average yield, as shown in table 4.1b, is 25t/ha for virus-tolerant varieties (Gempride and Mongal F_1), compared to 17t/ha for the virus-sensitive variety (Kher). This lower yield is particularly due to the drought that characterizes this zone. In Saint-Louis, producers benefit from the presence of a tomato cannery which provides inputs to farmers up front such as seeds and chemicals. The most common tomato variety the cannery releases to producers is the virus-tolerant Gempride, because it can withstand both wet and dry conditions that characterize this location. The average yield obtainable based on the cannery production report varies between 30 and 50 t/ha. As the adoption of the net-protected nursery is low, the change in tomato yield can be ascribed to the nature of the variety grown; that is, to its susceptibility to whitefly-transmitted viruses.

Table 4.1a: Tomato varieties grown and their yield in Mali

Varieties	Type	% of producers	Yield (t/ha)	Maximum yield obtained under experiments (MT/ha)*
Shasta	Resistant	18	15.52 (13.62)	64.3
H8804	Tolerant	12	11.94 (5.74)	32.7
Roma VF (w/ HFP)	Sensitive	20	17.52 (19.86)	17.15
Roma VF (w/o HFP)	Sensitive	50	3.34 (8.03)	17.15

Source: Surveys, June-July 2009
(*) From OPIB, Mali

Table 4.1b: Tomato varieties grown and their yield in Senegal

Varieties	Type	% of producers	Yield (t/ha)	Maximum yield obtained under experiments (MT/ha)*
Gempride	Resistant	24	30 (*)	50
Mongal F1	Tolerant	46	24.66 (18.71)	30
Kher	Sensitive	30	17.05 (20.17)	20

Source: Surveys, June-July 2009
(*) From ANCAR, Senegal

4.2. Determinants of adoption of IPM technologies

Adoption of new agricultural technologies is influenced by factors including household characteristics, technology characteristics, and the environment in which the technologies are implemented. The environment includes institutions such as extension facilities, community-based organizations, input and output markets, and credit. The following section presents an overview of the environment in which IPM technologies are implemented.

4.2.1. Households characteristics and technology environment

As indicated in table 4.2.1, among a total of 300 producers surveyed in Mali, 44% were female. The number of working persons in the household averages nine (four females and five males). Fifty-five percent of the respondents have no formal education while 24% of the respondents have completed either primary school (20%) or high school (4%), and 21% have received some other forms of education. On average, tomato production area is 0.37 ha per household. The seeds primarily are supplied by private dealers who provide seeds for 67% of the households. The average years of experience in tomato production is estimated at 11 years. Almost three-fourths of producers belong to a grassroots organization. Grassroots organizations in rural communities are a platform where producers are informed and also a place where information is diffused. The distance from the farm to the nearest extension office or from the farm to the local market averages five kilometers. Tomato producers have limited access to appropriate source of credit. In the sampled respondents, only 25% of producers have access to credit.

In Senegal, 24% were female, 90% are married and averaged 40 years of age. Forty four percent of the respondents have received adult education, while 20% have attended primary school, and 12% high school. Agriculture represents the main activity for almost all the respondents (98%) and more than 80% of producers belong to a rural grassroots organization. The average total number of working persons in the household is nine including four females and five males. The distance from farm to the nearest market or extension office averages five kilometers. Producers have a long experience in tomato production with an average of 18 years. The tomato acreage averages 0.50 hectare per household. Eighty percent of tomato producers rely on private dealers for purchasing tomato seeds whereas nine percent and seven percent of producers rely on the extension service or use seeds from the previous production.

Table 4.2.1: Characteristics of the sampled-households in Mali and Senegal

	Definition	Mali		Senegal	
Household's Characteristics		**N**	**Percent**	**N**	**Percent**
Gender	Male	167	56.0	218	76.2
	Female	131	44.0	68	23.8
Marital status	Single	13	4.4	20	7
	Married	271	90.9	258	90.2
	Divorced	1	0.3	1	0.3
	Widowed	13	4.4	7	2.4
Education	Illiterate (No education)	165	55.4	63	22.7
	Adult literacy	61	20.5	123	44.4
	Basic education	60	20.2	56	20.2
	High school	11	4	32	11.6
Ethnic group	Bambara/ Wolof	256	90.1	189	68.5
	Peulh & others	28	9.9	87	31.5
Major activity	Agriculture	291	99.3	262	98.1
	Small business	2	0.7	5	1.9
		Mean	**Std.**	**Mean**	**Std.**
Age of the respondent		40	11.04	45.40	11.80
Number of working male in the HH		5	3.29	4.61	3.71
Number of working female in the HH		4	3.47	4.25	5.32
Number of total working persons in the HH		9	6.39	8.62	6.73
Experience in tomato production (years)		11	8.3	18.16	10.30
Farm characteristics		**Mean**	**Std.**	**Mean**	**Std.**
Distance farm- nearest market (km)		5	4.33	10.93	12.71
Distance farm-nearest extension agent office (km)		5	5.36	7.30	6.45
Tomato area in hectare		0.37	0.46	0.50	0.89
Institutions		**N**	**Percent**	**N**	**Percent**
Membership	Membership	217	73.56	236	82.2
	No membership	78	26.44	51	17.8
Source of tomato seed	Self-production	24	8.05	19	6.6
	Extension service	47	15.77	25	8.7
	Private dealers	201	67.45	230	80
	Private dealers and Extension	26	8.72		
	Other sources			13	4.5
Access to credit		74	24.8	286	61.7
Contact with extension agent		94/149	63	286	23.9
Information on technologies					
% of users of HFP or NPN		125/149	84	286	6
Effectiveness of HFP		125/149	84	286	6
Participation to FFS-IPM	Male	62/149	42	286	9
	Female	30/149	20		

4.2.2. **Assessing determinants of farmers' participation in FFS for IPM**

The likely factors influencing producer participation in farmer field schools are estimated using a probit model. The results of this estimation are presented in table 4.2.2. Four factors are found significantly affect participation and include producer gender, marital status, literacy, and extension visits. Producer gender and contact with the extension agent are positively related to participation in training and are significant at the 1% level, whereas literacy and marital status are significant at the 10% and are both positively correlated with participation. The marginal effect of gender is 0.22, implying that the probability of participation is 22% higher for men compared to women. Likewise, the marginal effect of the variable "contact" or extension visits is 62.7% indicating that the probability of participating in training is nearly 63% higher for producers who are visited by the extension agent than others who are not visited. The marginal effect of "adult literacy" used as an indicator of producers' level of comprehension and of capacity to assimilate lessons learned during the training, is 0.18. This implies that the probability of farmer's participation in FFS training for farmers who can read and write in their local language is 18% greater than others who cannot. The marital status is positively related to the participation and has a marginal effect of 25%. This indicates that the tendency to participate in FFS training is 25% higher for married producers. These results indicate that the participation in FFS training for IPM is affected by producer gender, level of education, contact with extension agents and marital status.

Table 4.2.2: Probit results reporting the marginal effects of determinants of FFS participation in Mali

Ffsipm (dependent variable) = participation to FFS for IPM

Variables	x-bar	**Coefficient (Standard error)**	**Marginal effects (Standard error)**	**P>|z|**
Gender (dummy:1=male)	0.533	0.631*** (0.221)	0.224*** (0.075)	0.004
Log age (years)	3.664	-0.263 (0.447)	-0.095 (0.162)	0.556
Status (dummy: 1 = married)	0.910	0.855* (0.455)	0.247* (0.094)	0.060
Highschool (dummy)	0.038	-0.059 (0.600)	-0.021 (0.212)	0.922
Adultliteracy (dummy)	0.238	0.474* (0.247)	0.178* (0.095)	0.055
Active (numbers)	8.729	-0.014 (0.018)	-0.005 (0.007)	0.440
Contact (dummy)	0.333	1.798*** (0.239)	0.627 (0.066)	0.000
Membership (dummy)	0.729	0.150 (0.264)	0.053 (0.093)	0.570
Area (hectare)	0.281	0.331 (0.354)	0.120 (0.128)	0.349
Disextension (kilometers)	4.786	-0.028 (0.023)	-0.010 (0.008)	0.232
_cons		-1.247 (1.703)		0.464

Source: Surveys, June-July 2009

*** = 1% of significance level
** = 5% of significance level
* = 10% of significance level
Values in parenthesis indicate the standard error

4.2.3. **Factors affecting the host-free period adoption in Mali**

The determinants of adoption of a host-free period are modeled using the Heckman probit estimation with a Stata command **"heckprob."** The decision of adoption is not observed for producers who did not attend FFS training. The Heckman probit estimation accounts for the unobserved variables and evaluates determinants of adoption as if all producers are exposed to the technology. Table 4.2.3 shows the results of the Heckman probit estimation. The model also estimates the parameter rho, which measures the correlation of the residuals in the selection and the outcome equations, and a likelihood ratio (LR) test of rho = 0.

In table 4.2.3, the coefficient of rho is -0.05, which indicates that the error term in the selection equation is negatively correlated with the error term in the outcome equation. However, the model fails to reject the null hypothesis H_0: Rho=0 (Prob>chi2=0.92). Therefore, we can conclude that there is no correlation between the error terms of both selection and outcome equations. The selection bias mentioned as an issue in predicting determinants of the host-free period strategy is not pronounced, and therefore the parameters estimates are consistent and unbiased.

In addition, we estimate the marginal effect of the predictors in the outcomes equation using the STATA command ***"mfx compute, predict (pcond)"***, which provides the marginal effects for the probability of a positive outcome given the dependent variable being observed, Pr(depvar=1 | depvar_s=1). Our interpretation is based on the marginal effects, given their importance on the probability of adoption. The change in the probability of adoption represented in the model by (dF/dx) indicates the contribution of a given variable on the probability of adoption.

Results of the outcome equation in table 4.2.3 indicate that the most likely factors affecting the adoption of a host-free period are the producer's gender, age, contact with the extension agent, the number of working persons in the household, producer's degree of literacy and membership in the grassroots organization. The coefficient of the variables gender, literacy and age are negatively related to the probability of adoption and are significant at 10%, 5%, and 5% levels respectively. The negative sign of the coefficient associated with gender indicates that women are more likely to adopt the host-free strategy than men. The negative sign of the coefficient associated with age means that the older the farmer is, the less he is inclined to adopt, holding other parameters constant. The sign of the adult literacy variable is not consistent with our prediction. Conversely, the number of working persons in the household, the contact with extension, and membership in grassroots organization are positively related with the probability of adoption and are significant at 10%, 1% and 1% levels respectively. This implies that households with more working persons or a producer who has frequent visits with extension agents, or belongs to a grassroots has a higher propensity of adoption.

The marginal effect of gender, literacy, and age are -0.06, -0.13, and -0.13 respectively. The propensity of adoption for gender and literacy is 6% and 13% lower compared to their respective counterparts, holding other variables constant. The propensity of adoption associated with age is 0.13% lower for an additional year. Alternatively, the coefficients of number of working persons in the household, contact, and membership are 0.01, 0.09, and 0.21 implying that the propensity of adoption is 1%, 9% and 21% higher when the number of active members in the household increases, the producer is frequently visited by the extension agent, or belongs to the local grassroots organization.

Table 4.2.3: Results from the selector and outcome equations of the Heckman model of host-free period adoption

	Selection equation		Outcome equation		
	Coefficient Estimate	P>|z|	Coefficient Estimate	Marginal effect	P>|z|
Y_hfpadopt: Adoption of host-free period (= 1 for adopters)					
Gender (dummy:1=male)	0.075 (0.245)	0.758	-0.853* (0.473)	-0.060 (0.042)	0.071
Status (dummy)	0.154 (0.434)	0.723	0.852 (0.673)	0.115 (0.152)	0.206
Adultliteracy (dummy)	0.551* (0.310)	0.075	-1.026** (0.502)	-0.125 (0.096)	0.041
Highschool (dummy)	-0.674 (0.545)	0.216	1.097 (1.070)	0.033 (0.026)	0.305
Log age (years)	0.829 (0.433)	0.055	-1.819** (0.841)	-0.129 (0.085)	0.031
Active (number)	0.009 (0.020)	0.648	0.114* (0.060)	0.008 (0.005)	0.057
Contact (dummy)	1.180*** (0.267)	0.000	1.498*** (0.575)	0.092 (0.070)	0.009
Membership (dummy)	-0.456* (0.269)	0.090	1.478*** (0.465)	0.208 (0.118)	0.001
Area (hectare)	-3.740*** (0.508)	0.000	-	-0.008 (0.086)	-
Disextension (kilometers)	-0.105*** (0.037)	0.004	-	0.000 (0.002)	-
_cons	-1.805 (1.653)	0.275	5.793* (3.381)		0.087
/athrho	-0.048 (0.499)	0.923			
Rho	-0.048 (0.498)				

N (observations) = 240
n1 (censored obs) = 106
n2 (non censored obs) =134
Wald Chi square = 25.40
Log likelihood = -113.4948
LR test of indep. eqns. (rho = 0): chi2(1) = 0.01 Prob > chi2 = 0.9236

Source: Surveys data, 2009
***; **; * = 1%; 5% and 10% of significance level
Values in parenthesis indicate the standard error

4.2.4. **Factors affecting virus-tolerant variety adoption in Mali and Senegal**

As indicated in table 4.2.4a, the adoption of virus-tolerant varieties of tomato is affected by producer gender, marital status, education, the proportion of tomato revenue in the household income, tomato area, and seed costs in Mali. The coefficients of gender and tomato revenue are positive and are significant at the 1% level. The marginal effect of gender is 0.26, indicating that the probability for adopting virus-tolerant varieties is 26% higher for men than for women, holding other factors constant. The contribution of tomato revenue in the change of probability is marginal (0.4%). Conversely, tomato area, as well as the cost of improved seed lowers the probability of adoption and are significant at 1% and 5% levels, respectively. The marginal effect of the variable "tomato area" is -0.34 implying that a higher acreage may decrease the probability of adoption by 34%. This can be explained by the limited availability of improved seeds. Likewise, a higher cost associated with improved seeds tends to decrease the probability of adoption, but its effect is marginal (0.7%). This suggests that under a higher incidence of the virus, producers are willing to buy improved seeds. However, seed availability seems to be the main determinant decreasing adoption whereas producer gender and tomato revenue tend to favor it. Other factors such as marital status and basic education are also significant but their signs are not consistent with our prediction.

In Senegal, the determinants of adoption of virus-tolerant tomato seeds are presented in table 4.2.4b. The main factors affecting adoption of virus-tolerant seeds are, education, seed cost, experience in tomato losses caused by the virus, insecticide costs, and area of tomato. The probability of adoption is 21% greater for men than for women; and almost 27% greater for producers who are educated. The area of tomato decreases the probability by 21%. Likewise, experience in losses caused by the tomato virus decreases the probability of adoption by almost 25% for men, while for women; their experience in losses has no significant effect on the probability of adoption. Producers, especially men who experienced crop losses caused by viruses are less likely to adopt. Other factors such as the cost of improved seed, and the expenditure in pesticide are also significant but their contribution to the probability is marginal.

Table 4.2.4a: Probit model reporting marginal effects for the adoption of virus-tolerant variety adoption in Mali

	Mean	**Coefficient (Std. Err.)**	**P>z**	**dF/dx (Std. Err.)**	**P>z**
Y_tolerantVariety *(dependent variable)*	***0.278***				
Gender (dummy: male = 1)	0.571	1.794*** (0.549)	0.001	0.263*** (0.095)	0.001
Status (dummy)	0.906	-0.878** (0.448)	0.050	-0.208** (0.148)	0.050
Basiceduc (dummy)	0.403	-0.877** (0.402)	0.029	-0.096** (0.044)	0.029
Area (hectare)	0.429	-2.231*** (0.749)	0.003	-0.344*** (0.089)	0.003
Tomincome (%)	48.267	0.027*** (0.007)	0.000	0.004*** (0.002)	0.000
Sharearea (%)	14.220	-0.001 (0.009)	0.921	0.000 (0.001)	0.921
Market (%)	60.089	-0.004 (0.003)	0.147	-0.001 (0.001)	0.147
Credit (dummy)	0.257	-0.210 (0.304)	0.489	-0.030 (0.042)	0.489
Seedcost ($)	15.817	-0.043** (0.018)	0.018	-0.007** (0.003)	0.018
Men_Lossexp (dummy = Lossexp*Male)	0.503	-0.280 (0.487)	0.566	-0.043 (0.078)	0.566
_Cons		-0.640 (0.617)	0.300		
N	191				
Pseudo R^2	0.463				
Log likelihood	-59.498				

Source: Surveys, 2009
***; **; * = 1%; 5% and 10% of significance level
Values in parenthesis indicate standard errors

Table 4.2.4b: Probit model reporting marginal effects for adoption of virus-tolerant variety adoption in Senegal

	Mean	Coefficient (Std. Err.)	P>z	Marginal effect (Std. Err.)	P>z
y_tolerantvar (Dependent variable)	**0.240**				
Gender (dummy: male =1)	0.769	1.108** (0.568)	0.051	0.211** (0.077)	0.051
Status (dummy: married =1)	0.889	-0.048 (0.362)	0.895	-0.012 (0.096)	0.895
Basiceduc (dummy)	0.784	0.853*** (0.243)	0.000	0.265*** (0.084)	0.000
Area (hectare)	0.420	-0.825* (0.472)	0.080	-0.213* (0.122)	0.080
Tomincome (%)	33.563	-0.006 (0.006)	0.305	-0.002 (0.002)	0.305
Sharearea (%)	33.298	0.000 (0.006)	0.950	0.000 (0.002)	0.950
Market (%)	63.837	-0.003 (0.002)	0.235	-0.001 (0.001)	0.235
Credit (dummy)	0.668	-0.147 (0.239)	0.538	-0.039 (0.064)	0.538
Seedcost ($)	84.471	0.006*** (0.001)	0.000	0.001*** (0.000)	0.000
Men_Lossexp (dummy = Lossexp*Male)	0.726	-0.820* (0.482)	0.089	-0.244* (0.158)	0.089
Men_Pestcost (= Lossexp*Male) ($)	38.346	-0.014*** (0.006)	0.012	-0.004*** (0.001)	0.012
_Cons		-0.450 (0.472)	0.341		
N	208				
Pseudo R^2	48.65				
Log likelihood	-90.39				

Source: Surveys, 2009
***; **; * = 1%; 5% and 10% of significance level
Values in parenthesis indicate standard errors

4.2.5. **Discussion 1**

The participation of tomato producers in farmer field school (FFS) is one of the main components of the IPM program influencing the adoption of the technologies implemented. Prior to the implementation of the technologies, producers' awareness of tomato yellow leaf curl virus and its vector was raised through sensitization and training. The first step of the program has had a large influence on the adoption of the strategies implemented and on their effectiveness. The participation in training is gender-biased. Our data reveal that the participation in FFS training for IPM is dependent on gender, marital status, level of literacy, and visits with the extension agents. All these variables favor the participation in FFS training. Gender and visits with extension agents are the key factors of the participation because they are significant at 1% and have the large marginal effect. Currently in the country, the national extension office (IER/OPIB), in conjunction with USAID-Mali through IICEM project continues to expand the FFS training to other locations in order to reach more tomato producers. Information about the number of producers who participated in this training along with the locations covered is not released in this work.

Adoption of a host-free period is mainly affected by gender, age, and visits with the extension agent, the number of working persons in the household, the level of literacy, and membership. A membership of the farmer in grassroots associations is an excellent channel for diffusion of information and a source of opportunities where producers can learn from their peers. Membership is one of the key determinants in the diffusion of the technology. The significance of the coefficient associated with producer gender indicates that a host-free period strategy is gender-biased. Our results show that the coefficient on gender is negative, which means that the bias is towards women. Therefore, women are more inclined to adopt the host free strategy compared to men. In the context of a small-scale farming system, technologies are often more accessible to men compared to women. However, women play a significant role in such farming systems through their contribution to the labor force and marketing. Why was the proportion of women who adopted higher than men? This is probably due to the change observed in tomato production after whiteflies have become widespread across the region. Before the apparition of whiteflies, tomatoes were mostly grown by men who supplied to the local tomato cannery. As the incidence of the virus became higher, tomato production shifted significantly and the cannery ran out of business and went bankrupt. The majority of men abandoned tomato production for alternative crops. A large part of the production shifted to women who currently supply local markets today. Another reason that explains the relatively high probability of women in adopting a host-free period is the nature of the strategy itself. The host free technology consists of expanding tomato production for two months and does not require additional use of capital, or changes in the production system or in the reallocation of resources. The strategy aims to reduce the amount of insecticide used, and the production cost, while increasing tomato productivity. Since tomato producers, especially women, are low income farmers with limited access to credit to buy insecticides, they are more likely to adopt capital-saving technologies. Unfortunately data from the training organized in the project area prior to the implementation of the technology indicate that women represented only one-fifth of the total of 509 producers trained. As women are more likely to adopt IPM strategies than men, efforts that increase their participation in FFS training would be an advantage for the diffusion of the technologies across the region.

Another key determinant of the host-free period adoption is the contact with the extension agents. As was expected in our prediction, there is a significant difference in adoption between producers who are in close contact with extension agents compared to those who are not. The probability of adoption increases as the contact with the extension agent increases. It can be inferred from this result that the role of extension is key in the success of IPM technology adoption and diffusion.

The most likely factors affecting adoption of virus-tolerant tomato varieties in Mali is gender, marital status, education, tomato area, tomato revenue and seed cost. Men are more likely to adopt improved seeds than women because of the relatively higher cost of improved seeds. Seed cost is negatively associated with adoption. With respect to the price of local seed, which is one-tenth the price of the improved seed, the large majority of producers, especially women, are not able to afford it. During the surveys, it was reported that producers who grow improved seeds did not purchase them in the marketplace. Rather, the seeds were given to them by local extension agents as an incentive for adoption. Producers who are not granted improved seeds face a higher cost if they wish to grow them. The proportion of tomato revenue in the household's income is positively related to the adoption, implying that producers who adopt the virus-tolerant seeds have a higher income share compared to non-adopters. This share averages 66% for adopters compared to 42% of non-adopters. A mean comparison revealed that the difference between the share of income for adopters is significantly greater at the 1% level than the one for non-adopters. The adoption of virus-tolerant tomato seed could significantly improve household income.

More importantly, higher acreage reduced the probability of adoption. Tomato area averages 0.13hectare for adopters compared to 0.54 hectare for non-adopters. The mean comparison reveals a significant difference at the 1% level, implying that tomato area is significantly lower for adopters than for non-adopters. This is explained by the relatively high price of buying seeds to cover a large area of tomato. Likewise, the seed cost is negatively associated with the adoption. The average seed cost for virus-sensitive varieties is $10 for 100 grams compared to $190 per 100 grams for the virus-tolerant Shasta and $330 per 100 grams for the virus-tolerant H8804. That is, producers have a tendency to rely on the cheaper seed given their budget constraints.

In Senegal, key factors affecting the adoption of improved seeds are producer gender, education, tomato area, and men's experience in losses caused by the virus. The educational variable and being male favor adoption, whereas tomato area and men's experience reduce the chance of adoption. The control of tomato yellow leave curl viruses can be effective if the right technology is identified, tested for its appropriateness, and made available for adoption and diffusion. Yet, the net-protected nursery is one of the strategies implemented, but is not diffused for some reason that we still are unaware. However, as the host-free period is successful in Mali, which has globally similar agroecological conditions with Senegal, a similar strategy may also be effective in addressing tomato virus issues in Senegal.

4.3. Partial budget analysis of the adoption of IMP strategies

4.3.1. Benefits of the adoption of a host-free period in Mali

The benefits of the adoption of a host-free period are measured in terms of cost savings due to reduction in the amount of insecticides used, and in terms of the change in tomato yield. The virus-sensitive variety "Roma" is used as an indicator to assess the impact of the host-free period adoption on tomato production. This variety is chosen because it is widely grown (by 70% of producers), and the seed is relatively cheap and accessible to producers compared to the virus-tolerant ones. Before the implementation of the host-free period strategy, tomato producers rely exclusively on insecticides for whitefly control. As indicated in table 4.3.1, the number of insecticide applications varies from seven to 10 due to the high pressure of whiteflies. When the strategy is implemented and adopted, the number of pesticide sprays which initially varies between seven and 10 drops significantly to two or three sprays as the population of whiteflies has dropped substantially. This reduction in the number of sprays corresponds to 71% of reduction in the amount of insecticide used. The cost savings associated with this reduction is estimated at $200 per hectare, with a minimum of $169 and a maximum of $232.

In addition, the increase in yield of Roma after adopting the strategy is estimated at 14t/ha. With the average price of tomatoes estimated at $220 per ton, the average gain resulting from the change in yield is estimated to be $3320 per hectare, and ranges from $2,580 to $3,777 given the minimum and the maximum price. The proportionate change in revenue associated with the adoption is 739% compared to a situation where the strategy is not used.

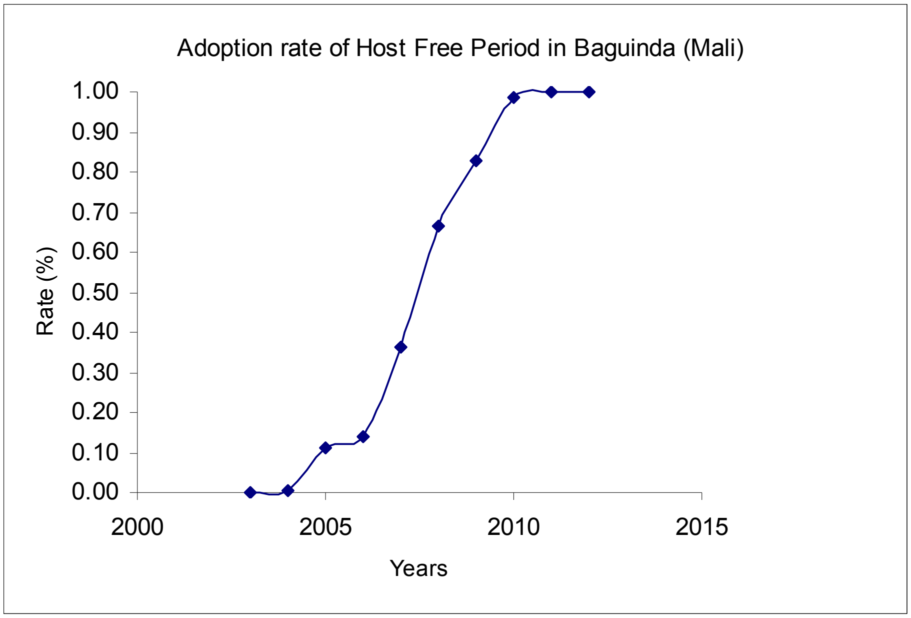
Table 4.3.1: Benefits of the adoption of host-free period (in $US)

		HFP users (a)	HFP non users (b)	Benefits of HFP (a) - (b)	Proportionate change
1	Yield (*)	17.52	3.34	14.18	425%
2	Price ($/ton)**	220 *(170 - 250)*	220 *(170 – 250)*	-	-
3	Revenue	3,854.4 *(2,978 - 4,380)*	734.8 *(568 - 835)*	$3,119.6 *(2,411 - 3,545)*	425%
4	Number of insecticide sprays	2 to 3	7 to 10	5 to 7	71%
5	Insecticide cost per application and per ha	34	34	-	-
6	Total cost of insecticide per ha (4x5)	85 *(68 to 102)*	285.56 *(237 – 334)*	-200.84 *(-169 to - 232)*	-71%
7	Gross margin (3-6)	3770 *(2910 to 4278)*	449.24 *(331 to 501)*	3320 *(2580 to 3777)*	739%

Source: Data from surveys, 2009
Note: Numbers in parentheses (.) indicate the range
(*) Yield of virus-sensitive variety "Roma"
(**) Price obtained from the local extension office (¢1≈ fcfa 4.5)

Using data from table 2.1, the estimated annual adoption rate of the host-free period averages 16%. This rate is used to predict the trends in adoption over time. Considering the establishment of an enforcement institution as part of the local extension policy, complete adoption may occur and can be reached by the year 2012 given the adoption rate of 16%. The goal of this institution is to sensitize and monitor tomato producers about the use of the host-free period. Every producer who plans to grow tomato must comply with this law at the risk of seeing his or her crop destroyed. Under such circumstances, we expect that all producers will respect the host-free period if they wish to produce tomato. Graphically, the adoption path is illustrated in figure 4.3.1 below. In this figure, the speed of diffusion of the technology is relatively low from 2004 to 2006. It becomes higher from 2006 to 2009 after the farmer's field schools training for IPM. For example in 2007, 509 producers (including 100 women) were trained on IPM technologies, and 22 local institutions (one per village) were installed. In addition, 40 extension agents including three women (USAID/IICEM, 2009) were trained on IPM technologies.

Figure 4.3.1: Adoption rate of host-free period for tomato production in Mali



Source: Data from surveys and IICEM/USAID, 2009

4.3.2. **Financial gains of virus-tolerant varieties in Mali**

Financial analysis of IPM strategies is conducted by evaluating the variable costs associated with tomato production. Variable costs include seeds, insecticides, fertilizers, and labor. The cost of capital such as land and equipment are not considered in evaluating the financial gain of the IPM technologies. The land is the local community property and is allocated to producers to grow rice. The rental cost associated with its usage is borne by both adopters and non-adopters. Moreover, equipment used for tomato production is similar for both adopters and non-adopters, since the adoption does not induce structural changes in the production system. Table 4.3.2a shows a partial budget for both adopters and non-adopters of improved tomato seeds. Results indicate that adoption of virus-tolerant tomato variety generates a profit of $2,116 and $1,188 per hectare for Shasta and H8804 respectively. The virus-sensitive variety Roma generates a profit of $2,736 per hectare under the host-free period, and a loss of $585 per hectare when the production occurs under non host-free period. Under the host-free period, results suggest that Roma is more profitable than the virus-tolerant Shasta or H8804. Table 4.3.2b summarizes partial budgets for both host-free period strategy and virus-tolerant tomato varieties. Our data indicate that adoption of virus-tolerant varieties (Shasta and H8804) generates a higher profit compared to Roma when the production occurs under whitefly pressure. This trend reverses when the production occurs under a host-free period. As the host-free period adoption is enforced, producers will be better off by growing Roma given its higher profitability over virus-tolerant ones.

Field experiments conducted with H8804 in a non-host-free period zone indicated that the potential yield obtainable with this variety is almost 45 tons with a profit of $6,637 per hectare and a rate of return of 102%. (See box 1). Producers may obtain a substantial profit if appropriate measures that could help reach the potential yield are taken.

Table 4.3.2a: Partial budget of tomato varieties in Mali

	Variables	Unit	VT variety (Shasta)	VT variety (H8804)	VS variety (with HFP)	VS (w/o HFP)
01	Yield	(ton/ha)	16 (64)	12 (33)	18	3
02	Price	($/ton)	220	220	220	220
03	Revenue (1*2)	($)	3414 (14146)	2627 (7194)	3854	735
04	Seeds	Quantity (grs)	100	100	100	100
05		Cost ($)	190	330	10	10
06	Fertilizers	Quantity of DAP(kg)	100	100	100	100
07		Cost ($)	100	100	100	100
08		Quantity of urea(kg)	150	150	150	150
09		Cost ($)	147	147	147	147
10		Quantity of manure (tons)	2	2	2	2
11		Cost ($)	27	27	27	27
12	Chemicals ($)	($)	85	85	85	286
13	Labor ($)	($)	750	750	750	750
14	**Total cost** (5+7+9+11+12+13)	**($)**	**1299**	**1439**	**1119**	**1319**
15	Gross margin *(Gross margin max)*	($)	2116 [a] (12,847)	1188 [b] (5755)	2736 [c]	-585 [d]
16	Rate of return		163%	83%	245%	--

(c)- (d) = $3321 = benefits per hectare of host-free period using virus-sensitive tomato variety (Roma)

(a)- (d) = $2701 (max: $13,432) = benefits per hectare by adopting virus-tolerant (Shasta) tomato variety without host-free period

(b)- (d) = $1773 (max: $6340 = benefits per hectare by adopting virus-tolerant (H8804) tomato variety without host-free period

Source: Data from surveys, 2009

Note: Numbers in parentheses (.) indicate the maximum values of an indicated parameter

Table 4.3.2b: Summary of the benefits of host-free period and virus-tolerant and sensitive tomato varieties in Mali

Benefits of IPM strategies		***Average gain ($)***	***Average gain per household***	***Maximum ($)***	***Maximum gain per household***
Benefits of HFP using virus-sensitive "Roma"		3,320	1,229	3,777	1,397
Gross margin of virus-tolerant "Shasta"		2,116	783	12,847	4,754
Gross margin of virus-tolerant "H8804"		1188	440	5,755	2,130
Gain by adopting virus-tolerant versus virus-sensitive	With HFP	(620)	(229)	10,112	3,741
	Without HFP	2,700	999	13,432	4,970
Gain by adopting virus-tolerant versus virus-sensitive	With HFP	(1,548)	(573)	3,020	1,117
	Without HFP	1,773	656	6,340	2,346

Source: Data from surveys, 2009

Note: Numbers in parentheses (.) indicate negative profits

Box 1: H8804 production under farm experiment			
Village of Dougourakoro, Kati (Mali)			
Tomato Variety: H8804			
Yield (ton/ ha)			***44.76***
Price ($293.16/ton)			
Revenue per ha			***13,121.69***
1. Nursery			
Cost elements	*Quantity*	*Per unit cost ($)*	*Amount ($)*
Seed (11g)	*11g*	*33.33*	*33.33*
Bed preparation	*1*	*0.56*	*0.56*
Weeding	*2*	*0.56*	*1.11*
Irrigation	*15*	*0.22*	*3.33*
Subtotal			*38.33*
2. Plantation			
Clearing	*2*	*2.22*	*4.44*
Plowing		*0.00*	*3.33*
Bed preparation	*1,5 day*	*2.22*	*3.33*
Sowing	*2pers*	*2.22*	*4.44*
Weeding		*0.00*	*23.33*
Watering	*38liters*	*1.56*	*59.11*
Mineral Fertilizer	*50kg*	*44.44*	*44.44*
Manure	*4*	*0.67*	*2.67*
Labor	*36 days*	*2.22*	*80.00*
Harvest	*15 pers*	*2.22*	*33.33*
Subtotal			*258.44*
Other investments			*247.90*
Total costs (for 0.084 ha)			*544.67*
Total cost per ha			***6484.17***
Total cost per household (average acreage = 0.37 ha)			***2399.14***
Gross margin per ha			***6637.52***
Gross margin per household (average = 0.37 ha)			***2455.88***
Marginal rate of return			***102.4%***
Source: Adapted from IICEM/USAID, 2009			

4.3.3. **Assessing the opportunity cost of implementing the host-free period**

The cost of a host-free program is evaluated by analyzing the effects of the change of the strategy on the production system. Changes are perceived in terms of land (re)allocation, and crop substitution within households. There are two cropping seasons in Mali within the year; the first season from January to May and the second from June to December. The host-free period strategy was developed for the beginning of the second cropping season from June to July, when the population of whiteflies is highest. As the tomato is one of the host plants of the virus vector, production occurring in June or July leads to multiplication of whiteflies. Without a host-free period, producers will either grow virus-tolerant varieties (for those who can afford for the seed) or grow substitute crops, or just simply wait until August to produce tomato. Because vegetables are grown in the same irrigated area after rice has been harvested, there is no perceptible conflict in land with other crops such as cereals. Grain production such as millet and sorghum occurs in the upland area and is rain fed. Considering the fact that the host-free period lasts two months, producing another vegetable in the area devoted to tomato within this period is not likely. Therefore, substitution of an alternative crop to tomato is not likely. With the existence of the local enforcement institution, growers who wish to plant virus-tolerant varieties will suffer losses associated with the host-free period strategy compared to those who plant the virus-sensitive variety because production may only occur after the host-free period has been observed. Anyhow, the use of virus-tolerant varieties is not a sustainable way to control the viruses as viruses may overtime overcome resistance. The cost of the host-free period is therefore what growers of virus-tolerant varieties lose by not producing tomato during this period.

Given the fact that the virus-sensitive tomato variety (Roma) cannot be grown when the whitefly population is highest, the opportunity cost of implementing a host-free period is evaluated in comparison with the benefits that could be obtained when the virus-tolerant tomatoes Shasta or H8804 is grown instead during the period of implementation. The evaluation consists of comparing the gain obtained under the host-free period (called "IPM Program") against the gain that could be obtained without the host-free period ("No IPM Program"). The difference in gain is explained by the difference in tomato price. Under No IPM Program, tomato is produced in June and harvested by September when the price is high due to the limited supply. This price is not observed and it is less likely to be obtained from farmers. The highest price of tomato is observed in December ($287 per ton, USAID/IICEM report, 2008) when the supply becomes low and is used instead as a proxy for the non-observed price in September. Using this price, the opportunity cost for implementing the host-free period is estimated to be $1046 per hectare (see table 4.3.3). This value is obtained by calculating the difference between the gross margin for growing virus-tolerant varieties under No IPM program and the gross margin under IPM program. This cost is compared against the gross margin obtained by producers who use virus-sensitive variety under IPM Program which is estimated to be $3,320 per hectare (see table 4.3.2b). The benefits per hectare resulting from adoption are greater than the losses observed by growing virus-tolerant varieties under the host-free period. In addition, the proportion of producers who rely on virus-tolerant varieties is lower than that of those who grow virus-sensitive varieties. The aggregated benefits resulting from the adoption are greater than the aggregated loss of not growing the virus-tolerant varieties. It is therefore profitable for producers to implement the host-free period strategy.

Table 4.3.3: Costs versus benefits of adopting the host-free period strategy

	Yield (ton/ha)	Price of tomato ($/ton)	Revenue ($)	Cost ($)	Gross margin ($)
With IPM Program	16	220	3,414	1,299	2,116
Without IPM program	16	287	4,460	1,299	3,162
Loss for not growing the virus-tolerant varieties ($/ha)				3,162 – 2116 = 1,046	
Benefits for host-free period adopters ($/ha)				= 3,320	

Source: Data from surveys, 2009

4.3.4. **Financial gains of adoption of net-protected nursery and virus-tolerant varieties in Senegal**

The adoption of the net-protected nursery has not occurred and the technology remains in the developmental stage in Senegal. Only 6% of the respondents use this strategy. The benefits associated with the adoption of this strategy are not assessed in this study given the small number of users and the difficulty for obtaining reliable data. The yield differential obtained by comparing virus-tolerant varieties to virus-sensitive ones can be therefore combined with the susceptibility of the latter to resist to TYLCV. For our analysis, the local variety "Kher," which is sensitive to TYLCV, is used as the basis for the analysis. The yield obtained from Kher is compared to the yield of Gempride and Mongal F_1, both virus-tolerant varieties. In table 4.3.4, the yields obtained from Gempride, Mongal F_1 and Kher are 30t/ha, 25t/ha, and 17t/ha respectively. With respect to the virus-sensitive variety, the gain in yield of the virus-tolerant varieties is 13t/ha and 8t/ha for Gempride and Mongal F_1 respectively. This corresponds to a proportionate change in yield of 45% and 76%. Meanwhile, the profit of virus-tolerant varieties, compared to the virus-sensitive one is estimated to be \$4,806 and \$1,789 for Gempride and Mongal, respectively. Using the maximum expected yield, the maximum benefit can reach \$7,322 for Gempride and \$2,339 for Mongal. With respect to the average area of tomato per household in Senegal (0.5ha), the adoption of the virus-tolerant varieties generated a profit of \$2,403 per household for Gempride (with a maximum of \$3,661), and \$895 (with a maximum of \$1,170) per household for Mongal F_1. Data in box 2 show a partial budget of Gempride, one of the main varieties produced for the tomato cannery "SOCAS" at Saint-Louis. As indicated in this box, the profit generated by the virus-tolerant tomato variety Gempride is low compared to the one calculated. The main reason is the low yield obtained in this area and the lower price of tomato. The average yield is 22 t/ha compared to the average of 30 tons for all the tomato production. This is due to the aridity of that particular area of Senegal.

Table 4.3.4: Production costs of tomato in Senegal

			Virus-tolerant (Gempride)	Virus-tolerant (Mongal F_1)	Virus-sensitive (Kher)
1	Yield (t/ha)		30 (50)	25 (30)	17 (20)
2	Price ($/ton)		230	230	230
3	**Revenue ($)**		**4094 (11500)**	**5672 (6900)**	**3922 (4600)**
4	Seed cost ($)		388	466	374
5	Fertilizers	*DAP*	678	678	678
6		*Urea*	56	56	56
7	Chemicals ($)		167	472	603
8	Labor ($)		116	116	116
9	Total cost		1405	1788	1827
10	Gross margin		6900 (10095)	3884 (5112)	2095 (2773)
11	Gain with respect to “Kher”		4,806 (7,322)	1,789 (2,339)	-
12	Gross margin per household (area = 0.5ha)		3450 (5048)	1942 (2556)	1047 (1387)
13	Gain with respect to “Kher” per household		2403 (3661)	895 (1169.5)	-
14	Marginal rate of return		491%	217%	115%

Source: Data from surveys, 2009

Note: Numbers in parentheses (.) indicate the maximum values of an indicated parameter

Box 2: Partial budget of Gempride at Saint-Louis (Senegal)

Region: Saint-Louis (Senegal)

Tomato Variety: Gempride

Acreage : 1 ha

Yield (ton/ ha)	***22.131***
Price ($/ton)	*104*
Revenue per ha	***2,301.62***
Cost elements	*Amount ($)*
Seed (11g)	*209*
Irrigation	*162*
Operational cost	*147*
Fertilizer	*395*
Chemicals	*186*
Equipments	*42*
Harvest	*30*
Transport	*22*
Interests	*67*
Membership	*50*
Others	*3*
Total cost	*1313*
Gross margin per ha	***988.49***
Marginal Rate of Return	***75.3%***

4.3.5. **Discussion 2**

Our results show that adoption of a host-free period has significantly reduced the amount of insecticides sprayed on tomato while increasing the level of production and revenue for households. The amount of pesticide is reduced by 71% which corresponds to a cost savings of $201 per hectare.

Some tomato producers complained about the low profit associated with the adoption of the host-free period, especially those who used virus-tolerant varieties. During our investigations, these producers reported that by adopting a host-free period, tomato is harvested in November or December where the price is relatively low compared to the price in September. The opportunity cost of implementing the host-free period for producers who used improved varieties is estimated at $1,046 per hectare whereas the benefits of adopting the strategy are estimated at $3,320 per hectare. Since the proportion of producers who grow virus-tolerant varieties is lower (30%) than that of virus-sensitive ones (70%), the aggregated benefits are greater than the aggregated costs. Promoting virus-tolerant varieties as strategies to reduce the loss caused by the virus will prevent a large number of low income producers (especially women) to grow tomato, given the relatively higher seed price. Assuming that virus-tolerant varieties become widely used in the near future, should producers prefer to rely on the use of virus-tolerant tomato varieties in order to maximize their profit and let the virus spread, or should they be forced to respect the host-free period through enforcements of local institutions in order to the keep whitefly population as low as possible? The answer may depend on the objective of the IPM program and the host country agricultural policy. We think that both the IPM program and beneficiary countries may seek to reduce the whitefly pressure.

The financial analysis revealed that the virus-sensitive variety Roma grown under a host-free period generated a higher profit ($3,320 per hectare) over virus-tolerant tomato varieties and a loss of $585 under virus pressure. This explains why most producers had given up tomato production when the host-free period was not identified. The profit varies from $1,188 to $2,116 per hectare for H8804 and Shasta respectively. The relatively higher price of virus-tolerant seeds is one of the reasons justifying such results. The seed cost of the virus-tolerant Shasta and H8804 is $190 and $330 per hectare respectively, compared to $10 per hectare for the virus-sensitive Roma. Moreover, virus-tolerant varieties recorded lower yields compared to Roma. The low yield recorded for virus-tolerant varieties can be explained by the level of inputs used. As improved varieties are fertilizer responsive, the amount of fertilizer used is relatively higher than the amount for local varieties. Given the lack of financial sources in rural areas, most producers are not able to afford such a chemical cost. The high cost of seed along with the low yield explains why the profitability of Shasta or H8804 is lower compared to Roma. However, as tomato viruses are overspread across the region, virus-tolerant tomato seeds can be promoted in areas where the host-free period is not yet implemented, as they generated higher profit which varies from $1,773 to $2,700.

In Senegal, the adoption of virus-tolerant varieties has generated substantial revenue for households ($1,789 to $4,806 per hectare). Although these results are satisfactory, the profit could be higher if an effective cropping strategy for tomato viruses control such as the host-free period, aiming at reducing the amount of pesticide used on tomato and therefore the production cost, is identified, implemented, and adopted. As mentioned previously, IPM activities are not successful in Senegal. The adoption of the net-protected nursery is not widespread and the benefits induced by its adoption are not evaluated due to the limited data available in our sample. To date, the vast majority of producers still rely on the use of different kind of pesticides for whiteflies control. The identification of the host-free period and its implementation along with the initiation of FFS training across tomato production areas in order to sensitize and sustain adoption of this practice are paramount. Moreover, exchange visits between producers exposed to the technologies in Mali, in particular those who have received FFS training for IPM on host-free period, and their peers in Senegal to share knowledge and experience could be envisioned in order to create incentives for producers and to sustain the adoption path in Senegal and Mali. This approach would facilitate the diffusion of the strategies since it is easier for farmers to learn from the experience of their peers. Beyond the peers-to-peers experience exchanges, the periodical visits of extension agents are also essential to provide advice to producers and to arouse their willingness to adopt.

4.4. Economic benefits of research to reduce tomato virus problems

The benefits of the IPM research are projected for each component of the program and for the whole country (Mali) over 18 years (2003-2020). Three scenarios are used and include the IPM cropping strategy (host-free period), virus-tolerant tomato varieties, and the overall IPM program. Our calculations present the net present value of the total revenue (NPV_R) accruing over the 18 years and the net present value of the benefits (NPV_B) after accounting for the research cost of the research-induced technologies. The benefits of virus-tolerant varieties are used as a proxy for the potential benefits of the development of transgenic tomato seeds. Sensitivity analyses are conducted using different rates of adoption, different values of the probability of adoption, and of the expected change in yield.

4.4.1. **Assessing the research benefits under a closed economy assumption**

Scenario 1: IPM cropping strategy (host-free period)

Under a closed economy assumption, the benefits of the IPM cropping strategy are first evaluated for the project site (Baguineda) where this strategy is implemented and then projected to the country. Tables 4.4.1a & 4.4.1b present the results.

Table 4.4.1a: Research benefits for the host-free period in the project site (Baguineda)

Maximum adoption rate	15%	30%	45%	60%	100%
NPV_R	834,132	1,705,234	2,613,307	3,558,350	6,259,211
NPV_B	718,306	1,589,408	2,497,481	3,442,524	6,143,385
IRR	120	250	370	500	840

Table 4.4.1b: Research benefits for the host-free period in the whole country (Mali)

Maximum adoption rate	15%	30%	45%	60%
NPV_R	3,734,263	7,506,700	11,317,311	15,099,237
NPV_B	3,425,394	7,197,831	11,008,442	14,790,368
IRR	206	414	621	829

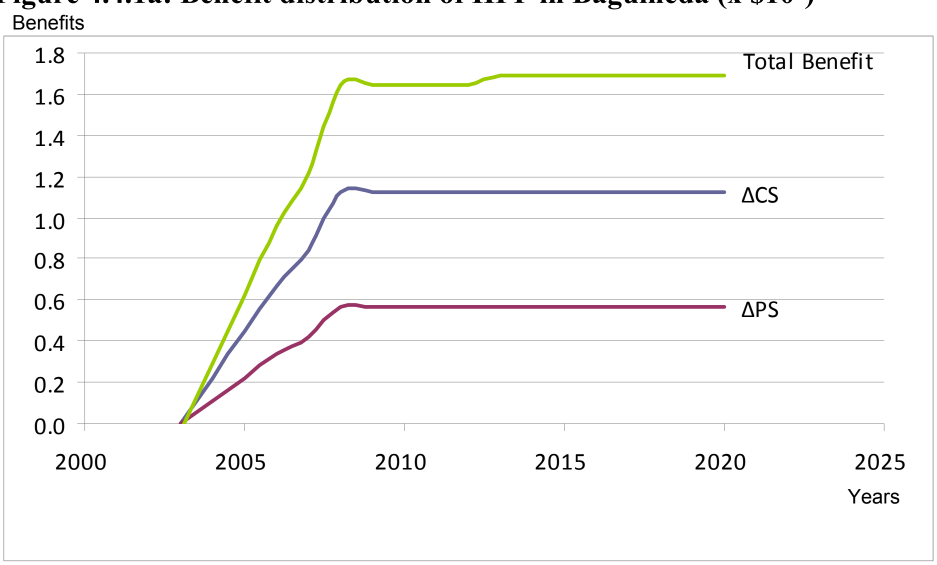
(*) ***See table B in annex 1 for more details***

Results from table 4.4.1a suggest that the net present value of the potential revenue, as well as of the potential benefits induced by the development of the host-free period in Baguineda increases with adoption rate. The NPV_R varies from $0.83 million with an adoption rate of 15% to $6.3 million with an adoption rate of 100%. Likewise, the NPV_B, that is, the net benefits after accounting for the costs incurred in the development of the technologies, varies from $0.7 million to $6.1 million for an adoption rate of 15% and 100% respectively. The internal rate of return (IRR), that is, the discount rate at which NPV equals zero varies in proportion to the adoption rate. The value of the IRR varies from 120% to 840% for a variation of adoption rate from 15% to 100%.

The research benefits resulting from the development of the host-free period is also projected at the country level. The present value of the total revenue varies from 3.7 million to $15 million when the adoption rate increases from 15% to 60%. Similarly, the net benefits increase from $3.4 million to $14.8 million for an adoption rate of 15% and 60% respectively. The IRR is estimated 206% for an adoption rate of 15% and increases to 829% with an adoption rate of 60%.

In terms of benefits distribution, both producers and consumers are well off. Producers gain one-third of the total benefits while consumers' gain two-thirds. Figure 4.4.1.a presents the trends of the benefits distribution over time. In this figure, both producer and consumer surplus curves have the same path. The producer surplus curve is beneath the consumer surplus curve because the ratio of the change in producer surplus over time to the change of consumer surplus over time (ΔPS/ ΔCS) is 0.5. The gain for producers comes from the reduction in production cost, in particular from the reduction in insecticide costs, and from the increment in tomato yield. Consumers' gains come from the reduction in tomato price due to the outward shift of the supply curve. The distribution of the benefits depends on the value of the parameter K or the magnitude of the vertical shift of the supply curves.

Figure 4.4.1a: Benefit distribution of HFP in Baguineda (x $\$10^6$)



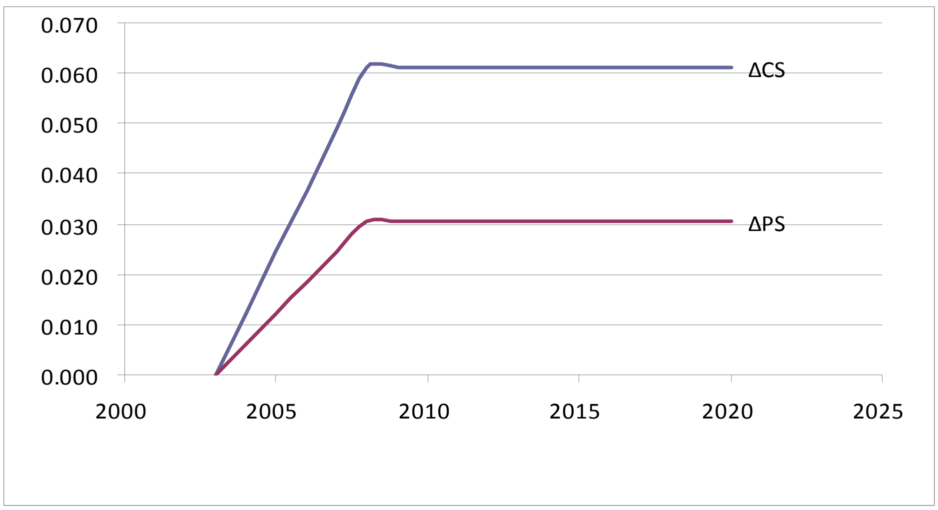
Scenario 2: Development of Virus-tolerant tomato seeds

The potential research benefits generated by the development of virus-tolerant seeds is projected at about $0.5 million for an adoption rate of 15%, and increases proportionally with the adoption rate. The maximum benefits expected can reach $3 million with an adoption rate of 60%. The internal rate of return varies from 30% for an adoption rate of 15% to 140% when the adoption rate reaches 60%. The distribution of the benefits (when the adoption rate is 60%) among producers and consumers, as indicated in figure 4.4.1b, follows a similar pathway as the case for the host-free period with a constant ratio ΔPS/ΔCS=0.5. The benefits reach their maximum five years after the research commences and when the adoption is maximal.

Table 4.4.1c: Research benefits of virus-tolerant variety in Mali

Maximum adoption rate	15%	30%	45%	60%
NPV_R	827,285	1,656,118	2,486,497	3,303,955
NPV_B	441,199	1,270,031	2,100,411	2,917,868
IRR	30%	70%	110%	140%

Figure 4.4.1b: Benefit distribution of virus-tolerant seeds in Mali (x $\$10^6$)



Scenario 3: Research benefits for the overall IPM program

The research benefits for the total IPM program are also projected until year 2020. A maximum adoption rate of 60% is used for the calculations. Sensitivity analyses are conducted by decreasing this rate to 45%, 30% and 15%. The proportionate change in input cost per hectare is set at 0.06, which is the sum of the change in input cost for both technologies. The probability of success used for the scenario is 0.45, the value obtained from scientists in the country for the overall IPM program. Using these parameters, the total benefits through year 2020 for the overall program are estimated at $4.8, $10.3, $15.9 and $21.6 million for 15%, 30%, 45%, and 60% of adoption rate respectively. The internal rate of return varies from 130% for an adoption rate of 15% to 540% for an adoption rate of 60%. The distribution of the benefits between producers and consumers is one-third of the total surplus to producers, compared to two-third for consumers. The ratio $\Delta PS/\Delta CS$ equals 0.5 and is constant over years.

Sensitivity analyses are also conducted by varying the expected yield change and the probability of success. The observed changes in benefits are presented in the figures below. Both the probability of success and the expected change in yield are linearly and positively related to the benefits induced by the IPM program. A change of the probability of success by one unit (from 0.45 to 0.44) reduces the overall IPM benefits by $0.5 million when the adoption rate of 60% is used. The change of the benefits resulting from the change in the probability of success varies proportionally with the adoption rate. For example, with an adoption rate of 30%, the reduction of the benefits for a change in one unit of the probability of success is $0.25 million.

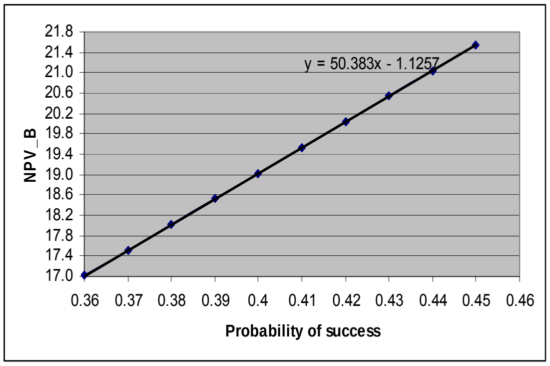
The change of the expected yield by one unit (from 0.63 to 0.62) decreases the overall benefits by $0.4 million for an adoption rate of 60%. With an adoption rate of 30%, the change in the benefits decreases by $0.2 million, and so on.

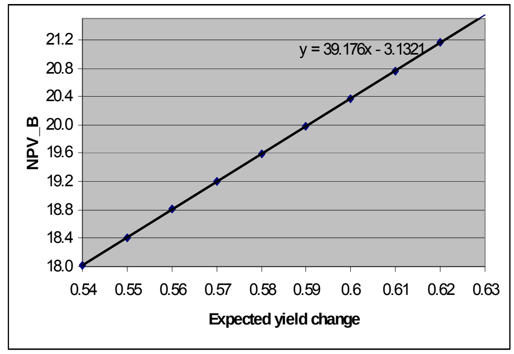
Table 4.4.1d: Benefits for the overall IPM program in closed economy market

Adoption rate	15%	30%	45%	60%
NPV_R	5,484,951	11,037,206	16,656,763	22,244,862
NPV_B	4,789,995	10,342,249	15,961,807	21,549,906
IRR	130	270	410	540

(*) ***See table D in annex 1 for more details***

Figure 4.4.1c: Effect of the change of the probability of success and the expected yield on the research benefits for overall IPM program (x $\$10^6$)





4.4.2. **Assessing the research benefits under an open economy assumption**

The research benefits under an open economy are assessed for both IPM cropping strategy, improved seeds, and the overall program. When the technologies are widespread, the potential benefits accruing through the year 2020 are estimated for each technology and for different adoption rates. With respect to the host-free period, results from table 4.4.1e indicate that the net benefits increase from $3.5 million to $15.4 million. The research benefits when the virus-tolerant varieties are developed and their adoption widespread is estimated at about $0.5 million for an adoption rate of 15% and increase proportionally up to nearly $3 million for an adoption rate of 60%. For the overall IPM program, the potential research benefits under the open economy assumption varies from $5 million to about $24 million when the adoption rate increases from 15% to 60%. In terms of the distribution, all the benefits go to producers because under open economy assumption, the demand curve for tomato is perfectly elastic (horizontal line). A sensitivity analysis with the expected yield change or the probability of success provides similar results to that obtained under the closed economy assumption.

Table 4.4.1e: Benefits of IPM program in Mali in open economy market

Adoption rate		Host-free period	Virus-tolerant seeds	Overall IPM program
15%	NPV_R	3,772,437	828,832	5,786,296
	NPV_B	3,463,568	442,746	5,091,340
30%	NPV_R	7,659,396	1,662,306	11,791,553
	NPV_B	7,350,527	1,276,220	11,096,597
45%	NPV_R	11,660,878	2,500,422	18,015,770
	NPV_B	11,352,009	2,114,335	17,320,814
60%	NPV_R	15,705,571	3,328,529	24,347,420
	NPV_B	15,396,702	2,942,442	23,652,464

(*) ***See table F, G and H in annex 2 for more details***

4.4.3. **Discussion 3**

This chapter explores the potential research benefits in developing IPM in West Africa. The benefits are projected from 2003, the year of the implementation of the technologies to 2020 for each component of the IPM program including the IPM cropping strategy (host-free period), the development of virus-tolerant varieties, and the overall IPM program. The benefits are calculated for both the closed and the open economies. Sensitivity analyses are conducted using different adoption rates, and by gradually varying the probability of success and the expected change in yield.

The research benefits under both the closed and the open economies increase proportionally to the adoption rate. Under the closed economy assumption, the potential net benefits induced by the adoption of the host-free period vary from $0.7 million to $6.1 million with an adoption rate of 15% and 100% in Baguineda. When the strategy is overspread in the country, the benefits are projected at $3.4 million for an adoption rate of 14.8% and increases proportionally to $15 million when the adoption rate increases. Likewise, the development of virus-tolerant seeds generates a benefit of $0.5 to $3 million with the same range of adoption rate. With respect to the overall IPM program, the benefits projected through the year 2020 are estimated at $4.8, $10.3, $15.9, and $21.6 million for 15%, 30%, 45%, and 60% adoption rates respectively. The distribution of the benefits follows the same pathway for the host-free period, the improved seeds, and for the overall IPM program. Producers capture one-third of the total benefits while consumers gain the remaining two-thirds.

Under the open economy assumption and for the same range of adoption rate, the net benefits vary from $3.5 million to $15.4 million for the host-free period, from $0.5

million to $3 million for the virus-tolerant varieties, and from $5 million to $24 million for the overall IPM program. That is, the benefits increase proportionally with the adoption rate.

Sensitivity analyses of the research benefits of the overall IPM program under the closed economy assumption are conducted with different values of the probability of success and with different values of the expected yield change. The results reveal that the benefit is linearly related to the change in probability. Increasing the probability of adoption by one more unit (for example from 0.44 to 0.45), increases the net benefits by $0.5 million when an adoption rate of 60% is assumed. This increment is proportional to the adoption rate. Increasing the expected change in yield by one unit (or from 0.62 to 0.63) increases the net benefits by $0.4 million, $0.2 million, and 0.1 million for an adoption rate of 60%, 30%, and 15% respectively.

Given the assumed elasticities for a closed economy, the distribution of the benefits shows that consumers gain more than producers when the technologies are developed. For our calculations, the elasticities of supply and demand are set at 1.0 and 0.5 respectively. On the consumer side, the tomato is an inelastic good, and thus less likely to increase in quantity as the price decreases. Therefore, consumers are likely to benefit more than producers because of the reduction in price.

5. General conclusion and policy implications

5.1. General conclusion

This study assesses the economic impact of the IPM technologies for tomato to address the tomato yellow leaf curl virus problem in West Africa. Prior to the arrival of the TYLCV, fresh tomatoes were produced for both local and regional markets throughout the West African countries and represented a significant source of income for households. During the last decade, TYLCV became a severe constraint to tomato production and reduced the yield and the area under tomato production throughout the region. The production shifted remarkably across the region and converted a net exporting country into a net importing one for both fresh and canned tomatoes. The integrated pest management (IPM) program implemented at the early stage of virus appearance addressed the tomato virus problem by identifying effective technologies that could help producers offset production losses caused by the virus. Technologies developed by the program included a host-free period for the virus vector (whiteflies) and the development of virus-tolerant varieties. A baseline survey was conducted in Mali and Senegal in 2006 to assess farmers' perceptions of the virus incidence on tomato yield, and on the change in variable costs. Interviews were also conducted with scientists and industrial experts involved in tomato production and processing about their opinions on probabilities of technical success and changes in input costs. They were also asked to identify time lags related to research, regulatory mechanisms and adoption of improved varieties. Additional surveys were carried-out in June-July 2009 on the effectiveness of the technologies implemented. The main findings of these investigations are summarized as follows:

The adoption of the host-free period is widespread in the location where the strategy is implemented. More than 75% of producers have adopted the strategy in Baguineda (Mali), and about 20% of producers relied on virus-tolerant varieties. In Senegal, the net-protected nursery strategy is not successful. However, the virus-tolerant varieties are grown by 70% of the producers surveyed.

Our data indicate that adoption of the host-free period reduces the amount of insecticides sprayed on tomato by 71% in Mali. The cost savings associated with this reduction in pesticide use is estimated approximately at $200 per hectare. The cost-benefit analysis indicates that the virus-tolerant varieties (H8804, Shasta) are profitable and generate a profit ranging from $1,188 per hectare for H8804 to $2,116 per hectare for Shasta. The profitability is greater when tomato production occurs under a host-free period. The virus-sensitive variety “Roma” is profitable only when it is grown under the host-free period. It generates a higher profit of $3,320 per hectare over the virus-tolerant varieties H8804 and Shasta due to its relatively low seed cost ($10 per hectare compared to $190 and $330 per hectare for Shasta and H8804 respectively). In terms of changes in yield, the adoption of the host-free period induces a significant change in production. Using the virus-sensitive variety, Roma, as a reference, the change in production varies from 3.34 tons per hectare when the production occurs without the host-free period to 14.18 tons per hectare under the host-free period, or a proportionate change of 425%. These results confirm our hypothesis 1.a, which states that the adoption of IPM strategies reduces tomato losses and pesticides cost by at least 50%.

In Senegal, the net-protected nursery was not successful. The proportionate change in yield resulting from the adoption of virus-tolerant varieties was estimated at 76% and

44% for the virus-tolerant Gempride and Mongal F1; the virus-sensitive variety Kher was used as the base. The cost-benefit analysis indicated that both varieties are profitable over the virus-sensitive one. The profit generated varied from $1,789 to $4,806 per hectare. As the adoption of improved seeds is budget-constrained compared to the traditional seeds, the identification of a cropping practice such as the host-free period is essential to allow the majority of producers to continue growing tomato with a reduced amount of pesticides.

The main factors affecting the host-free period adoption in Mali are gender, age, contact with the extension agent, the number of working persons in the household, the level of literacy and membership in community organizations. Some of these factors are mentioned in our second hypothesis. A membership in grassroots associations is an excellent channel of diffusion of reliable information and a source of opportunities where producers can learn from their peers. A membership is one of the key determinants in the diffusion of the technology. The coefficient of gender is negative indicating that women have a higher propensity to adopt the host-free period than men. The probability of adoption increases with extension agent visits. Extension agents therefore play a key role in the success of the IPM technologies adoption. The most likely factors affecting the virus-tolerant tomato variety adoption are gender, marital status, education, tomato area, tomato revenue and seed cost. The analysis reveals that men are more likely to adopt improved seeds than women, and that the seed cost is negatively associated with adoption. The proportion of tomato revenue in household income is positively related to adoption, revealing that producers who adopt the virus-tolerant seeds have a higher income share from tomatoes than non-adopters. In Senegal, adoption of improved seeds is influenced by a producer’s gender, education, tomato area, and experience in losses caused by the virus. The level of education and gender (being male) favored the adoption, whereas the area of tomato and the experience of the producer reduced the chance of adoption.

The research benefits induced by IPM were projected for each technology implemented and for the overall IPM program in Mali through the year 2020. The benefits were calculated for both closed and open economies. Our results indicated that the benefits increased proportionally with the adoption rate. Under the closed economy assumption, the benefits induced by the adoption of the host-free period ranged from $0.7 million to $6 million in Baguineda, and from $3.4 million to $14.8 million for the whole country for an adoption rate varying from 15% to 60%. With the same range of adoption rate, the benefits were estimated at $0.5 million to $3 million for the virus-tolerant seeds, and from $4.8 million to $21.6 million for the overall IPM program. Under the open economy assumption, the potential benefits varied from $3.5 million to $15.4 million for the host-free period, from $0.5 million to $3 million for the virus-tolerant varieties, and from $5 million to $24 million for the overall IPM program. The distribution pattern of the benefits between producers and consumers was similar for each component of the program as well as for the overall IPM program both respectively. Both producers and consumers are better-off and share one-third and two-thirds of the total benefits respectively. This confirms our third hypothesis. Sensitivity analyses conducted with different values of the probability of success and the expected change in yield indicated that the net benefits are linearly related to the expected change of yield.

Meanwhile, the distribution of the benefits showed that consumers gained more than producers. This is explained by the price elasticities of supply and demand for tomato.

The results suggest that the implementation of IPM technologies in other West Africa countries would have a significant impact on both individuals and societal welfare.

5.2. Policy implications

Our results support policies aimed at increasing the adoption rate of IPM technologies or helping producers reach the potential expected change in yields. One policy might include the increase in participation of women in FFS training for IPM as they are more inclined to adopt the host-free period strategy than men. Moreover, the membership of producers in grassroots association which is a platform where information is diffused needs to be promoted to sustain the projected adoption path. Furthermore, the adoption of the host-free period is effective in controlling the whiteflies population by increasing tomato yield significantly, and generating substantial profit for farmers. A policy aimed at spreading this strategy across the tomato production areas in Mali, in Senegal, and in the rest of West African countries may enhance the production of tomato and improve rural livelihoods.

Our results showed that the virus-tolerant varieties were also profitable over the visus-sensitive ones, especially in the location where no strategy was envisioned to reduce the pressure of whiteflies population. The development of virus-tolerant tomato varieties may also be considered as one of the key research activities where efforts might be concentrated. However, because viruses continue to evolve to overcome resistance, the development of resistant varieties may be burdensome for research centers already characterized by limited resources. Even though some countries choose this option, the adoption of new varieties, as shown in our analysis, is budget-constrained for producers. Under this option, a policy aimed at relaxing such a constraint for producers is necessary and may include producer's access to seeds markets through affordable source of credits. Moreover, the development of appropriate seed markets by private dealers or farmers' associations may be one way to facilitate producers' access to seeds.

Adoption is to a great extent dependent on extension support. The strengthening of extension by providing more facilities to support and monitor producers should be encouraged. This is possible when the country considers the IPM strategies as one of its research priorities. To date, the IPM strategies are not yet a national crop protection priority in most African countries. In the countries where the use of the strategies is becoming part of the agricultural research policy, the allocation of resources and facilities is not sufficient to support the adoption and diffusion of the strategies. With regard to market size, the development of the cannery to remove the excess supply of fresh tomato, or access to new markets in the region, might be alternatives to explore to sustain the adoption of the IPM strategies.

To efficiently address tomato virus problems in West Africa and to obtain the successful development of IPM technologies, an interlocking virtual network between both public and private sectors is paramount. In this network the national research programs, international development institutions, input dealers, industrial experts, and producers need to join forces to take into account all the different aspects of the technology development, the production, the processing, and the marketing. Such a network brings all the players together and helps the national research institutions and international agencies understand the complexity of the problem and design appropriate technologies, the producers to be aware of the technology under development, and input dealers to make available the technologies (especially seed multiplication and distribution) to the producers. Still in the region, there are joint efforts from development agencies and national research programs focusing on the diffusion of the existing technologies. Such collaborative efforts should be used as a platform for the diffusion and the sustainability of the technologies. Beyond this platform, exchange visits between producers exposed to the technologies in Mali, in particular those who received FFS training for IPM on host-free period, and their peers in other West African countries where the strategies encounter some difficulties due to reasons evoked previously, to share knowledge and experience should be envisioned. As it is easier for farmers to learn from the experience of their peers, this approach would facilitate the diffusion of the IPM strategies across the West Africa.

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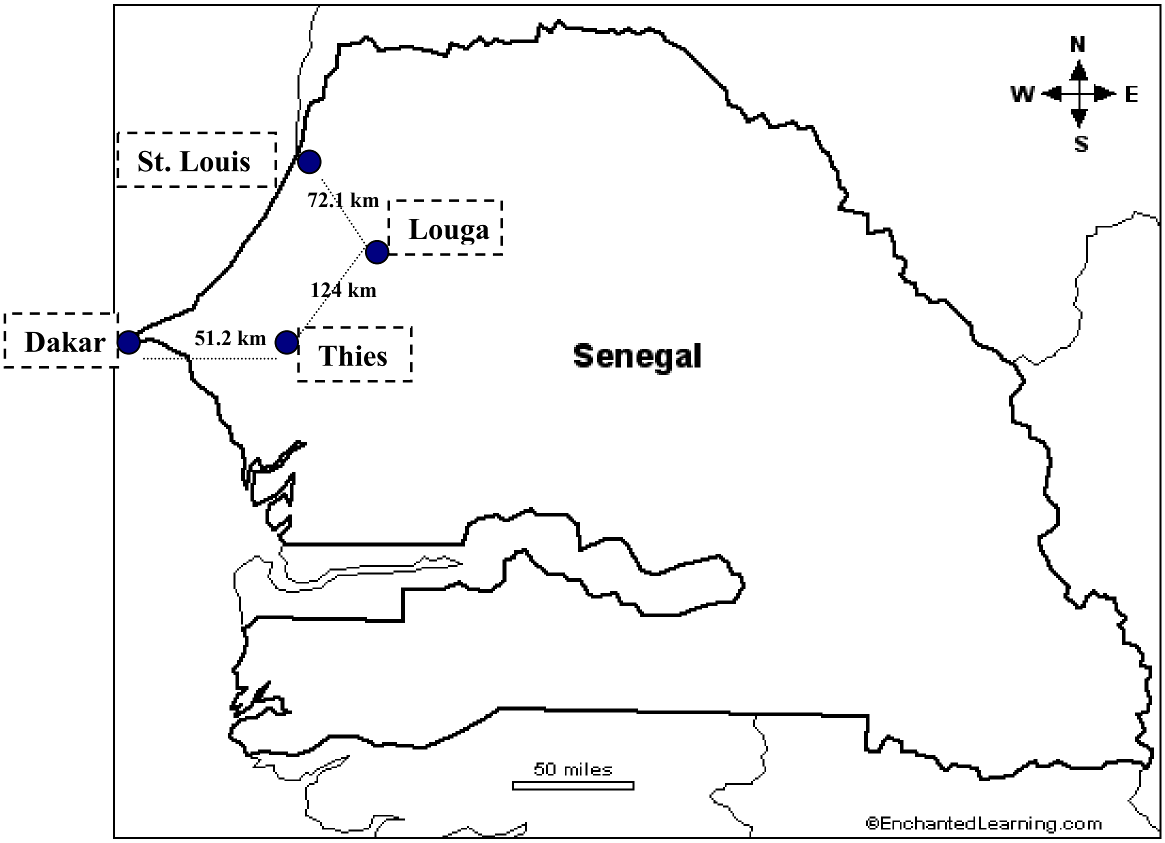
Appendix A: Countries in West Africa where surveys were conducted

Source: Map extracted from http://enchantedlearning.com/geography/africa/

Appendix B: Surveys location in Mali

Source: Map extracted from http://enchantedlearning.com/geography/africa/

Appendix C: Surveys location in Senegal



Source: Map extracted from http://enchantedlearning.com/geography/africa/

Appendix D: Determinants of adoption models

Probit model for factors influencing farmers' participation in FFS in Mali

```
Probit regression                                 Number of obs   =        218
                                                  LR chi2(5)      =      21.65
                                                  Prob > chi2     =     0.0006
Log likelihood = -133.52273                       Pseudo R2       =     0.0750
```

ffsipm	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
gender	.5900836	.1811335	3.26	0.001	.2350684	.9450987
age	-.0063347	.0083437	-0.76	0.448	-.0226881	.0100187
adulteduc	.4178589	.2112752	1.98	0.048	.0037671	.8319507
highschool	.1730373	.4748463	0.36	0.716	-.7576444	1.103719
disextension	-.0389475	.0179737	-2.17	0.030	-.0741753	-.0037196
_cons	-.3127098	.3636518	-0.86	0.390	-1.025454	.4000347

```
Probit regression, reporting marginal effects           Number of obs =    218
                                                        LR chi2(5)    =  21.65
                                                        Prob > chi2   = 0.0006
Log likelihood = -133.52273                             Pseudo R2     = 0.0750
```

ffsipm	dF/dx	Std. Err.	z	P>|z|	x-bar	[95%	C.I.]
gender*	.2178145	.0646562	3.26	0.001	.53211	.091091	.344538
age	-.0023837	.0031378	-0.76	0.448	40.3349	-.008534	.003766
adulte~c*	.1612798	.0824721	1.98	0.048	.229358	-.000363	.322922
highsc~l*	.0666291	.1862185	0.36	0.716	.036697	-.298353	.431611
disext~n	-.0146554	.0067547	-2.17	0.030	4.87615	-.027894	-.001416
obs. P	.3761468						
pred. P	.3661929	(at x-bar)					

(*) dF/dx is for discrete change of dummy variable from 0 to 1
z and P>|z| correspond to the test of the underlying coefficient being 0

Heckman probit results for estimation of determinants of adoption of host-free period in Mali

```
Probit model with sample selection                Number of obs      =       240
                                                  Censored obs       =       106
                                                  Uncensored obs     =       134

                                                  Wald chi2(8)       =     25.40
Log likelihood = -113.4948                        Prob > chi2        =    0.0013
```

	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
y_hfpadopt						
gender	-.8529437	.4732109	-1.80	0.071	-1.78042	.0745327
married	.8516041	.6734675	1.26	0.206	-.468368	2.171576
adulteduc	-1.025643	.5023201	-2.04	0.041	-2.010172	-.0411137
highschool	1.097185	1.07034	1.03	0.305	-1.000643	3.195014
lage	-1.818741	.8410937	-2.16	0.031	-3.467255	-.1702279
actifst	.114486	.0602667	1.90	0.057	-.0036346	.2326065
contact	1.498137	.5750514	2.61	0.009	.371057	2.625217
membershipf	1.47839	.4649499	3.18	0.001	.5671044	2.389675
_cons	5.792929	3.380522	1.71	0.087	-.8327732	12.41863
select						
gender	.0752648	.2447465	0.31	0.758	-.4044296	.5549592
married	.1535146	.433869	0.35	0.723	-.6968529	1.003882
adulteduc	.5512953	.3099807	1.78	0.075	-.0562557	1.158846
highschool	-.6736571	.5447472	-1.24	0.216	-1.741342	.3940279
lage	.8293661	.4330415	1.92	0.055	-.0193796	1.678112
actifst	.0090291	.019769	0.46	0.648	-.0297174	.0477757
contact	1.179634	.2671702	4.42	0.000	.65599	1.703278
membershipf	-.4559874	.2685796	-1.70	0.090	-.9823936	.0704189
acreage	-3.740431	.5076835	-7.37	0.000	-4.735473	-2.74539
disextensi~f	-.1053416	.0368674	-2.86	0.004	-.1776005	-.0330828
_cons	-1.805367	1.65343	-1.09	0.275	-5.046029	1.435295
/athrho	-.0482493	.4993506	-0.10	0.923	-1.026958	.9304598
rho	-.0482119	.4981899			-.7726856	.7308082

LR test of indep. eqns. (rho = 0): chi2(1) = 0.01 Prob > chi2 = 0.9236

```
. mfx compute, predict (pcond)

Marginal effects after heckprob
      y  = Pr(y_hfpadopt=1|select=1) (predict, pcond)
         =  .96794173
```

variable	dy/dx	Std. Err.	z	P>|z|	[95%	C.I.]	X
gender*	-.0600618	.04213	-1.43	0.154	-.142636	.022513	.558333
married*	.1154417	.15154	0.76	0.446	-.181572	.412455	.9125
adulte~c*	-.1254271	.0958	-1.31	0.190	-.313184	.062329	.216667
highsc~l*	.0334461	.026	1.29	0.198	-.01752	.084412	.041667
lage	-.1290025	.08518	-1.51	0.130	-.295952	.037947	3.65829
actifst	.0082555	.00512	1.61	0.107	-.001782	.018293	8.83333
contact*	.0923623	.06951	1.33	0.184	-.043875	.2286	.35
member~f*	.2079623	.11771	1.77	0.077	-.022744	.438669	.7375
acreage	-.0082513	.08643	-0.10	0.924	-.177657	.161154	.326632
disext~f	-.0002324	.00245	-0.09	0.924	-.005035	.00457	4.54583

(*) dy/dx is for discrete change of dummy variable from 0 to 1

Probit model reporting marginal effects for the adoption of virus-tolerant variety adoption in Mali

sum

Variable	Obs	Mean	Std. Dev.	Min	Max
gender	194	.5773196	.4952636	0	1
married	194	.9020619	.298	0	1
basiceduc	194	.1958763	.3979006	0	1
tomincome	194	48.44845	24.91582	1	100
sharetomcrop	194	14.18557	17.38609	0	100
credit	194	.2525773	.4356147	0	1
seedcost	191	15.81675	11.99443	1	67
acreage	194	.4235309	.4936194	.01	3
lossgender	194	.5103093	.5011871	0	1
market	194	60.70103	47.03921	0	100
y_tolerant~r	194	.2783505	.4493465	0	1

```
Probit regression                                 Number of obs   =        191
                                                  LR chi2(10)     =     102.67
                                                  Prob > chi2     =     0.0000
Log likelihood = -59.498271                       Pseudo R2       =     0.4632
```

y_tolerant~r	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
gender	1.793869	.5488457	3.27	0.001	.7181507	2.869586
married	-.8780519	.4476556	-1.96	0.050	-1.755441	-.000663
basiceduc	-.8768739	.4020277	-2.18	0.029	-1.664834	-.0889142
tomincome	.027307	.0069782	3.91	0.000	.01363	.040984
sharetomcrop	-.0008405	.008524	-0.10	0.921	-.0175472	.0158661
credit	-.210104	.3039121	-0.69	0.489	-.8057608	.3855528
seedcost	-.043078	.0181859	-2.37	0.018	-.0787218	-.0074342
acreage	-2.230567	.748957	-2.98	0.003	-3.698496	-.7626385
lossgender	-.279812	.487089	-0.57	0.566	-1.234489	.6748648
market	-.0044158	.0030484	-1.45	0.147	-.0103906	.0015589
_cons	-.6401463	.6174962	-1.04	0.300	-1.850417	.570124

Note: 2 failures and 0 successes completely determined.

```
Probit regression, reporting marginal effects           Number of obs =    191
                                                        LR chi2(10)   = 102.67
                                                        Prob > chi2   = 0.0000
Log likelihood = -59.498271                             Pseudo R2     = 0.4632
```

y_tole~r	dF/dx	Std. Err.	z	P>|z|	x-bar	[95%	C.I.]
gender*	.2634171	.0952621	3.27	0.001	.570681	.076707	.450127
married*	-.2079647	.14833	-1.96	0.050	.905759	-.498686	.082757
basice~c*	-.0956084	.0441434	-2.18	0.029	.198953	-.182128	-.009089
tominc~e	.0042143	.0015096	3.91	0.000	48.267	.001256	.007173
sharet~p	-.0001297	.0013231	-0.10	0.921	14.2199	-.002723	.002463
credit*	-.0302362	.0419896	-0.69	0.489	.256545	-.112534	.052062
seedcost	-.0066482	.0030504	-2.37	0.018	15.8168	-.012627	-.00067
acreage	-.3442407	.0886735	-2.98	0.003	.428979	-.518038	-.170444
lossge~r*	-.0433525	.0775176	-0.57	0.566	.502618	-.195284	.108579
market	-.0006815	.0005212	-1.45	0.147	60.089	-.001703	.00034
obs. P	.2670157						
pred. P	.0840692	(at x-bar)					

(*) dF/dx is for discrete change of dummy variable from 0 to 1
z and P>|z| correspond to the test of the underlying coefficient being 0

Probit model reporting marginal effects for the adoption of virus-tolerant variety adoption in Senegal

Sum

Variable	Obs	Mean	Std. Dev.	Min	Max
ytolerantvar	208	.2403846	.428348	0	1
gender	208	.7692308	.4223415	0	1
married	208	.8894231	.3143641	0	1
basiceduc	208	.2067308	.4059377	0	1
tomincome	208	33.5625	19.41751	4	95
sharetomcrop	208	33.29808	18.60413	0	100
credit	208	.6682692	.4719708	0	1
seedcost	208	84.47115	118.4625	2	667
acreage	208	.4202596	.3895011	.005	2
market	208	63.83654	47.54771	0	100
lossgender	208	.7259615	.4471045	0	1
pestgender	208	38.34615	43.49852	0	228

```
Probit regression                                 Number of obs   =        208
                                                  LR chi2(11)     =      48.65
                                                  Prob > chi2     =     0.0000
Log likelihood = -90.393153                       Pseudo R2       =     0.2120
```

ytolerantvar	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
gender	1.107744	.5682412	1.95	0.051	-.0059881	2.221477
married	-.0475879	.3619565	-0.13	0.895	-.7570096	.6618338
basiceduc	.8532556	.2427944	3.51	0.000	.3773874	1.329124
tomincome	-.0064197	.0062546	-1.03	0.305	-.0186785	.0058391
sharetomcrop	.0003753	.0060087	0.06	0.950	-.0114015	.0121521
credit	-.1471536	.2388436	-0.62	0.538	-.6152784	.3209712
seedcost	.0057572	.001354	4.25	0.000	.0031034	.008411
acreage	-.8250454	.471647	-1.75	0.080	-1.749457	.0993658
market	-.002731	.0022983	-1.19	0.235	-.0072356	.0017736
lossgender	-.8197027	.4815141	-1.70	0.089	-1.763453	.1240477
pestgender	-.0140994	.0056265	-2.51	0.012	-.0251271	-.0030717
_cons	-.4497833	.4722586	-0.95	0.341	-1.375393	.4758266

```
Probit regression, reporting marginal effects           Number of obs =    208
                                                        LR chi2(11)   =  48.65
                                                        Prob > chi2   = 0.0000
Log likelihood = -90.393153                             Pseudo R2     = 0.2120
```

ytoler~r	dF/dx	Std. Err.	z	P>|z|	x-bar	[95%	C.I.]
gender*	.211401	.0765998	1.95	0.051	.769231	.061268	.361534
married*	-.0124698	.0963971	-0.13	0.895	.889423	-.201405	.176465
basice~c*	.264884	.0843905	3.51	0.000	.206731	.099482	.430286
tominc~e	-.0016536	.0015901	-1.03	0.305	33.5625	-.00477	.001463
sharet~p	.0000967	.001547	0.06	0.950	33.2981	-.002935	.003129
credit*	-.0387745	.0641059	-0.62	0.538	.668269	-.16442	.086871
seedcost	.001483	.0003287	4.25	0.000	84.4712	.000839	.002127
acreage	-.2125171	.122356	-1.75	0.080	.42026	-.452331	.027296
market	-.0007035	.0005826	-1.19	0.235	63.8365	-.001845	.000438
lossge~r*	-.2437884	.1576396	-1.70	0.089	.725962	-.552756	.06518
pestge~r	-.0036318	.0013483	-2.51	0.012	38.3462	-.006274	-.000989
obs. P	.2403846						
pred. P	.1747937	(at x-bar)					

```
(*) dF/dx is for discrete change of dummy variable from 0 to 1
    z and P>|z| correspond to the test of the underlying coefficient being 0
```

Appendix E: Economic surplus spreadsheets

The spreadsheet use to assess the benefits result from the development of tomato technologies in Mali is presented in table A. Tables B though E present the results for the closed economy assumption and tables F though H present the results for the open economy assumption using a maximum adoption rate of 60%

Table A: Spreadsheet used to assess the research benefits of IPM technologies in a closed economy

A	B	C	D	E	F	G	H	I	J
Year	**ε**	η	**Max. Yield change**	**Gross cost Change/ ton**	**Input cost change/ha**	**Input cost change/ ton**	**Net cost change**	**Prob. Of success**	**Adopt. Rate**

K	L	M	N	O	P	Q	R	S	T	U	V	W
Depreciation Rate	**K**	**Price**	**Z**	**Quantity**	ΔTS	ΔCS	ΔPS	**Research cost**	**Benefits**	NPV	IRR	NPV 2

Column A:	Year	Number of years used to project the research annual benefits. The projection is done for 15 years (2007-2021)
Column B:	Supply elasticity	The value of price elasticity of supply (**ε**)
Column C:	Demand elasticity	The absolute value of the price elasticity of demand (**η**)
Column D:	% of yield change	Maximum percent expected in yield change per ha E(*Y*) due to the adoption of technologies
Column E:	% of gross cost change per ton	Gross proportion of the reduction in marginal cost per ton of output, E(*Y*)/**ε.**
Column F:	% change in input per ha	Proportion of change in variable input costs per hectare, E(C), if any, to achieve the expected yield change
Column G:	% change in input per ton of output	Proportionate input cost change per hectare to a proportionate input cost change per ton of output, E(C)/(1 + E(*Y*))
Column H:	Net percent change in cost per ton of output	Indicate the effect of variable input cost changes associated with the yield change to give the maximum potential net change in marginal cost per ton of output
Column I:	Probability of success	The probability (*p*) of the research success to achieve the expected yield change E(*Y*)
Column J:	Adoption rate	Adoption rate (A_t), defined in relation to years t, from the begin of the research
Column K:	Depreciation rate	Assumed equals zero in this study
Column L:	% of shift of supply curve	Proportionate shift down in the supply curve in period t due to research, K_t
Column M:	Proportionate decrease in price in year t	Reduction in price relative to its initial value, due to the supply shift, $Z_t = K_t\, \varepsilon/(\varepsilon + \eta)$
Column N	Price	Price of tomato in Mali in US$. This price remains constant at P_0 because we assume that the production of

		tomato in Mali do not influence world price
Column O:	Quantity	Quantity (ton) of tomato in Mali before the research commences. This quantity is constant and equal to the base quantity.
Column P	Change in total surplus in year t (ΔTS)	The change in total surplus, ΔTS = column M x column N x column O x [1 + (column N x column Q)]
Column Q	Change in consumer surplus in year t (ΔCS)	
Column R	Change in producer surplus in year t (ΔPS)	
Column S	Research cost	Costs required for the development of IPM technologies
Column T	Benefits	ΔTS – Research cost (Net benefits induced by the adoption of the IPM technologies)
Column U	NPV	Net present Value = net gain induced by the research on IPM strategies technologies
Column V	IRR	
Column W	NPV2	

E1: Closed Economy: Economic surplus results for Host-free period adoption in Baguineda (Mali)

YEAR	e	n	YIELD CHANGE	PROPOR. COST CHANGE	I. COST CHANGE PER HA.	I. COST CHANGE PER TON	NET CHANGE	PROB OF SUCCESS	ADOPT RATE	Depre Rate	K	Z	PRICE	QUANTITY	ΔTS	ΔCS	ΔPS	COST	BENEFIT	NPV	IRR	NPV2
2003	1.00	0.50	1.00	1.00	0.04	0.020	0.980	1.00	0.00	1.00	0.000	0.000	220.00	2800.00	0.00	0.00	0.00	15000.00	-15000.00			
2004	1.00	0.50	1.00	1.00	0.04	0.020	0.980	1.00	0.12	1.00	0.118	0.078	220.00	2800.00	73861.46	49240.97	24620.49	15000.00	58861.46			
2005	1.00	0.50	1.00	1.00	0.04	0.020	0.980	1.00	0.24	1.00	0.235	0.157	220.00	2800.00	150562.62	100375.08	50187.54	15000.00	135562.62			
2006	1.00	0.50	1.00	1.00	0.04	0.020	0.980	1.00	0.36	1.00	0.353	0.235	220.00	2800.00	230103.50	153402.33	76701.17	15000.00	215103.50			
2007	1.00	0.50	1.00	1.00	0.04	0.020	0.980	1.00	0.48	1.00	0.470	0.314	220.00	2800.00	312484.09	208322.72	104161.36	15000.00	297484.09	**3442524.43**	4.96	**3558350.45**
2008	1.00	0.50	1.00	1.00	0.04	0.020	0.980	1.00	0.60	1.00	0.588	0.392	220.00	2800.00	397704.38	265136.26	132568.13	15000.00	382704.38			
2009	1.00	0.50	1.00	1.00	0.04	0.020	0.980	1.00	0.60	1.00	0.588	0.392	220.00	2800.00	397704.38	265136.26	132568.13	15000.00	382704.38			
2010	1.00	0.50	1.00	1.00	0.04	0.020	0.980	1.00	0.60	1.00	0.588	0.392	220.00	2800.00	397704.38	265136.26	132568.13	15000.00	382704.38			
2011	1.00	0.50	1.00	1.00	0.04	0.020	0.980	1.00	0.60	1.00	0.588	0.392	220.00	2800.00	397704.38	265136.26	132568.13	15000.00	382704.38			
2012	1.00	0.50	1.00	1.00	0.04	0.020	0.980	1.00	0.60	1.00	0.588	0.392	220.00	2800.00	397704.38	265136.26	132568.13	15000.00	382704.38			
2013	1.00	0.50	1.00	1.00	0.04	0.020	0.980	1.00	0.60	1.00	0.588	0.392	220.00	2800.00	397704.38	265136.26	132568.13		397704.38			
2014	1.00	0.50	1.00	1.00	0.04	0.020	0.980	1.00	0.60	1.00	0.588	0.392	220.00	2800.00	397704.38	265136.26	132568.13		397704.38			
2015	1.00	0.50	1.00	1.00	0.04	0.020	0.980	1.00	0.60	1.00	0.588	0.392	220.00	2800.00	397704.38	265136.26	132568.13		397704.38			
2016	1.00	0.50	1.00	1.00	0.04	0.020	0.980	1.00	0.60	1.00	0.588	0.392	220.00	2800.00	397704.38	265136.26	132568.13		397704.38			
2017	1.00	0.50	1.00	1.00	0.04	0.020	0.980	1.00	0.60	1.00	0.588	0.392	220.00	2800.00	397704.38	265136.26	132568.13		397704.38			
2018	1.00	0.50	1.00	1.00	0.04	0.020	0.980	1.00	0.60	1.00	0.588	0.392	220.00	2800.00	397704.38	265136.26	132568.13		397704.38			
2019	1.00	0.50	1.00	1.00	0.04	0.020	0.980	1.00	0.60	1.00	0.588	0.392	220.00	2800.00	397704.38	265136.26	132568.13		397704.38			
2020	1.00	0.50	1.00	1.00	0.04	0.020	0.980	1.00	0.60	1.00	0.588	0.392	220.00	2800.00	397704.38	265136.26	132568.13		397704.38			

E2: Closed Economy: Economic surplus results for Host-free period adoption in the country (Mali)

YEAR	e	n	YIELD CHANGE	GROSS PROPOR. COST CHANGE	PROPOR. I. COST CHANGE PER HA.	PROPOR. I. COST CHANGE PER TON	NET CHANGE	PROB OF SUCCESS	ADOPT RATE	Depre Rate	K	Z	PRICE	QUANTITY	ΔTS	ΔCS	ΔPS	COST	BENEFIT	NPV	IRR	NPV2
2003	1.00	0.50	0.52	0.52	0.04	0.026	0.494	0.45	0.00	1.00	0.000	0.000	220.00	56260.00	0.00	0.00	0.00	40000.00	-40000.00			
2004	1.00	0.50	0.52	0.52	0.04	0.026	0.494	0.45	0.12	1.00	0.027	0.018	220.00	56260.00	331429.20	220952.80	110476.40	40000.00	291429.20			
2005	1.00	0.50	0.52	0.52	0.04	0.026	0.494	0.45	0.24	1.00	0.053	0.036	220.00	56260.00	665790.56	443860.37	221930.19	40000.00	625790.56			
2006	1.00	0.50	0.52	0.52	0.04	0.026	0.494	0.45	0.36	1.00	0.080	0.053	220.00	56260.00	1003084.07	668722.72	334361.36	40000.00	963084.07			
2007	1.00	0.50	0.52	0.52	0.04	0.026	0.494	0.45	0.45	1.00	0.100	0.067	220.00	56260.00	1257978.44	838652.29	419326.15	40000.00	1217978.44	**14790367.59**	8.29	**15099236.99**
2008	1.00	0.50	0.52	0.52	0.04	0.026	0.494	0.45	0.60	1.00	0.133	0.089	220.00	56260.00	1686467.57	1124311.72	562155.86	40000.00	1646467.57			
2009	1.00	0.50	0.52	0.52	0.04	0.026	0.494	0.45	0.60	1.00	0.133	0.089	220.00	56260.00	1686467.57	1124311.72	562155.86	40000.00	1646467.57			
2010	1.00	0.50	0.52	0.52	0.04	0.026	0.494	0.45	0.60	1.00	0.133	0.089	220.00	56260.00	1686467.57	1124311.72	562155.86	40000.00	1646467.57			
2011	1.00	0.50	0.52	0.52	0.04	0.026	0.494	0.45	0.60	1.00	0.133	0.089	220.00	56260.00	1686467.57	1124311.72	562155.86	40000.00	1646467.57			
2012	1.00	0.50	0.52	0.52	0.04	0.026	0.494	0.45	0.60	1.00	0.133	0.089	220.00	56260.00	1686467.57	1124311.72	562155.86	40000.00	1646467.57			
2013	1.00	0.50	0.52	0.52	0.04	0.026	0.494	0.45	0.60	1.00	0.133	0.089	220.00	56260.00	1686467.57	1124311.72	562155.86		1686467.57			
2014	1.00	0.50	0.52	0.52	0.04	0.026	0.494	0.45	0.60	1.00	0.133	0.089	220.00	56260.00	1686467.57	1124311.72	562155.86		1686467.57			
2015	1.00	0.50	0.52	0.52	0.04	0.026	0.494	0.45	0.60	1.00	0.133	0.089	220.00	56260.00	1686467.57	1124311.72	562155.86		1686467.57			
2016	1.00	0.50	0.52	0.52	0.04	0.026	0.494	0.45	0.60	1.00	0.133	0.089	220.00	56260.00	1686467.57	1124311.72	562155.86		1686467.57			
2017	1.00	0.50	0.52	0.52	0.04	0.026	0.494	0.45	0.60	1.00	0.133	0.089	220.00	56260.00	1686467.57	1124311.72	562155.86		1686467.57			
2018	1.00	0.50	0.52	0.52	0.04	0.026	0.494	0.45	0.60	1.00	0.133	0.089	220.00	56260.00	1686467.57	1124311.72	562155.86		1686467.57			
2019	1.00	0.50	0.52	0.52	0.04	0.026	0.494	0.45	0.60	1.00	0.133	0.089	220.00	56260.00	1686467.57	1124311.72	562155.86		1686467.57			
2020	1.00	0.50	0.52	0.52	0.04	0.026	0.494	0.45	0.60	1.00	0.133	0.089	220.00	56260.00	1686467.57	1124311.72	562155.86		1686467.57			

E3: Closed Economy: Economic surplus results for Virus-tolerant tomato varieties in Mali

YEAR	e	n	YIELD CHANC	GROSS PROPOR. COST CHANGE	PROPOR. I. COST CHANGE PER HA.	PROPOR. I. COST CHANGE PER TON	NET CHANGE	PROB OF SUCCESS	ADOPT RATE	Depre Rate	K	Z	PRICE	QUANTITY	ΔTS	ΔCS	ΔPS	COST	BENEFIT	NPV	IRR	NPV2
2003	1.00	0.50	0.11	0.11	0.02	0.018	0.092	0.44	0.00	1.00	0.000	0.000	220.00	68703.00	0.00	0.00	0.00	50000.00	-50000.00	2917868.32	1.45	3303955.07
2004	1.00	0.50	0.11	0.11	0.02	0.018	0.092	0.44	0.12	1.00	0.005	0.003	220.00	68703.00	73466.01	48977.34	24488.67	50000.00	23466.01			
2005	1.00	0.50	0.11	0.11	0.02	0.018	0.092	0.44	0.24	1.00	0.010	0.006	220.00	68703.00	147050.86	98033.91	49016.95	50000.00	97050.86			
2006	1.00	0.50	0.11	0.11	0.02	0.018	0.092	0.44	0.36	1.00	0.015	0.010	220.00	68703.00	220754.54	147169.70	73584.85	50000.00	170754.54			
2007	1.00	0.50	0.11	0.11	0.02	0.018	0.092	0.44	0.45	1.00	0.018	0.012	220.00	68703.00	276110.29	184073.53	92036.76	50000.00	226110.29			
2008	1.00	0.50	0.11	0.11	0.02	0.018	0.092	0.44	0.60	1.00	0.024	0.016	220.00	68703.00	368518.42	245678.95	122839.47	50000.00	318518.42			
2009	1.00	0.50	0.11	0.11	0.02	0.018	0.092	0.44	0.60	1.00	0.024	0.016	220.00	68703.00	368518.42	245678.95	122839.47	50000.00	318518.42			
2010	1.00	0.50	0.11	0.11	0.02	0.018	0.092	0.44	0.60	1.00	0.024	0.016	220.00	68703.00	368518.42	245678.95	122839.47	50000.00	318518.42			
2011	1.00	0.50	0.11	0.11	0.02	0.018	0.092	0.44	0.60	1.00	0.024	0.016	220.00	68703.00	368518.42	245678.95	122839.47	50000.00	318518.42			
2012	1.00	0.50	0.11	0.11	0.02	0.018	0.092	0.44	0.60	1.00	0.024	0.016	220.00	68703.00	368518.42	245678.95	122839.47	50000.00	318518.42			
2013	1.00	0.50	0.11	0.11	0.02	0.018	0.092	0.44	0.60	1.00	0.024	0.016	220.00	68703.00	368518.42	245678.95	122839.47		368518.42			
2014	1.00	0.50	0.11	0.11	0.02	0.018	0.092	0.44	0.60	1.00	0.024	0.016	220.00	68703.00	368518.42	245678.95	122839.47		368518.42			
2015	1.00	0.50	0.11	0.11	0.02	0.018	0.092	0.44	0.60	1.00	0.024	0.016	220.00	68703.00	368518.42	245678.95	122839.47		368518.42			
2016	1.00	0.50	0.11	0.11	0.02	0.018	0.092	0.44	0.60	1.00	0.024	0.016	220.00	68703.00	368518.42	245678.95	122839.47		368518.42			
2017	1.00	0.50	0.11	0.11	0.02	0.018	0.092	0.44	0.60	1.00	0.024	0.016	220.00	68703.00	368518.42	245678.95	122839.47		368518.42			
2018	1.00	0.50	0.11	0.11	0.02	0.018	0.092	0.44	0.60	1.00	0.024	0.016	220.00	68703.00	368518.42	245678.95	122839.47		368518.42			
2019	1.00	0.50	0.11	0.11	0.02	0.018	0.092	0.44	0.60	1.00	0.024	0.016	220.00	68703.00	368518.42	245678.95	122839.47		368518.42			
2020	1.00	0.50	0.11	0.11	0.02	0.018	0.092	0.44	0.60	1.00	0.024	0.016	220.00	68703.00	368518.42	245678.95	122839.47		368518.42			

E4: Closed Economy: Economic surplus results for overall IPM technologies (Virus-tolerant tomato varieties and Host-free period)

YEAR	e	n	YIELD CHANC	GROSS PROPOR. COST CHANGE	PROPOR. I. COST CHANGE PER HA.	PROPOR. I. COST CHANGE PER TON	NET CHANGE	PROB OF SUCCESS	ADOPT RATE	Depre Rate	K	Z	PRICE	QUANTITY	ΔTS	ΔCS	ΔPS	COST	BENEFIT	NPV	IRR	NPV2
2003	1.00	0.50	0.63	0.63	0.06	0.037	0.593	0.45	0.00	1.00	0.000	0.000	220.00	68703.00	0.00	0.00	0.00	90000.00	-90000.00	**21549905.63**	5.41	**22244861.77**
2004	1.00	0.50	0.63	0.63	0.06	0.037	0.593	0.45	0.12	1.00	0.032	0.021	220.00	68703.00	486741.64	324494.43	162247.21	90000.00	396741.64			
2005	1.00	0.50	0.63	0.63	0.06	0.037	0.593	0.45	0.24	1.00	0.064	0.043	220.00	68703.00	978652.83	652435.22	326217.61	90000.00	888652.83			
2006	1.00	0.50	0.63	0.63	0.06	0.037	0.593	0.45	0.36	1.00	0.096	0.064	220.00	68703.00	1475733.57	983822.38	491911.19	90000.00	1385733.57			
2007	1.00	0.50	0.63	0.63	0.06	0.037	0.593	0.45	0.45	1.00	0.120	0.080	220.00	68703.00	1851936.64	1234624.43	617312.21	90000.00	1761936.64			
2008	1.00	0.50	0.63	0.63	0.06	0.037	0.593	0.45	0.60	1.00	0.160	0.107	220.00	68703.00	2485403.69	1656935.80	828467.90	90000.00	2395403.69			
2009	1.00	0.50	0.63	0.63	0.06	0.037	0.593	0.45	0.60	1.00	0.160	0.107	220.00	68703.00	2485403.69	1656935.80	828467.90	90000.00	2395403.69			
2010	1.00	0.50	0.63	0.63	0.06	0.037	0.593	0.45	0.60	1.00	0.160	0.107	220.00	68703.00	2485403.69	1656935.80	828467.90	90000.00	2395403.69			
2011	1.00	0.50	0.63	0.63	0.06	0.037	0.593	0.45	0.60	1.00	0.160	0.107	220.00	68703.00	2485403.69	1656935.80	828467.90	90000.00	2395403.69			
2012	1.00	0.50	0.63	0.63	0.06	0.037	0.593	0.45	0.60	1.00	0.160	0.107	220.00	68703.00	2485403.69	1656935.80	828467.90	90000.00	2395403.69			
2013	1.00	0.50	0.63	0.63	0.06	0.037	0.593	0.45	0.60	1.00	0.160	0.107	220.00	68703.00	2485403.69	1656935.80	828467.90		2485403.69			
2014	1.00	0.50	0.63	0.63	0.06	0.037	0.593	0.45	0.60	1.00	0.160	0.107	220.00	68703.00	2485403.69	1656935.80	828467.90		2485403.69			
2015	1.00	0.50	0.63	0.63	0.06	0.037	0.593	0.45	0.60	1.00	0.160	0.107	220.00	68703.00	2485403.69	1656935.80	828467.90		2485403.69			
2016	1.00	0.50	0.63	0.63	0.06	0.037	0.593	0.45	0.60	1.00	0.160	0.107	220.00	68703.00	2485403.69	1656935.80	828467.90		2485403.69			
2017	1.00	0.50	0.63	0.63	0.06	0.037	0.593	0.45	0.60	1.00	0.160	0.107	220.00	68703.00	2485403.69	1656935.80	828467.90		2485403.69			
2018	1.00	0.50	0.63	0.63	0.06	0.037	0.593	0.45	0.60	1.00	0.160	0.107	220.00	68703.00	2485403.69	1656935.80	828467.90		2485403.69			
2019	1.00	0.50	0.63	0.63	0.06	0.037	0.593	0.45	0.60	1.00	0.160	0.107	220.00	68703.00	2485403.69	1656935.80	828467.90		2485403.69			
2020	1.00	0.50	0.63	0.63	0.06	0.037	0.593	0.45	0.60	1.00	0.160	0.107	220.00	68703.00	2485403.69	1656935.80	828467.90		2485403.69			

E5: Open economy: Economic surplus results for host-free period

YEAR	e	n	YIELD CHANGE	GROSS PROPOR. COST CHANGE	PROPOR. I. COST CHANGE PER HA.	PROPOR. I. COST CHANGE PER TON	NET CHANGE	PROB OF SUCCESS	ADOPT RATE	Depre Rate	K	PRICE	EXOGEN. OUTPUT CHANGE	QUANTITY	CTS	COST	BENEFIT	NPV	NPV2
2003	1.00	0.50	0.52	0.52	0.04	0.026	0.494	0.45	0.00	1.00	0.000	220.00	0.01	56260.00	0.00	40000.00	-40000.00		
2004	1.00	0.50	0.52	0.52	0.04	0.026	0.494	0.45	0.12	1.00	0.027	220.00	0.01	56260.00	334361.36	40000.00	294361.36	15396701.77	15705571.17
2005	1.00	0.50	0.52	0.52	0.04	0.026	0.494	0.45	0.24	1.00	0.053	220.00	0.01	56260.00	677519.19	40000.00	637519.19		
2006	1.00	0.50	0.52	0.52	0.04	0.026	0.494	0.45	0.36	1.00	0.080	220.00	0.01	56260.00	1029473.48	40000.00	989473.48		
2007	1.00	0.50	0.52	0.52	0.04	0.026	0.494	0.45	0.45	1.00	0.100	220.00	0.01	56260.00	1299211.89	40000.00	1259211.89		
2008	1.00	0.50	0.52	0.52	0.04	0.026	0.494	0.45	0.60	1.00	0.133	220.00	0.01	56260.00	1759771.49	40000.00	1719771.49		
2009	1.00	0.50	0.52	0.52	0.04	0.026	0.494	0.45	0.60	1.00	0.133	220.00	0.01	56260.00	1759771.49	40000.00	1719771.49		
2010	1.00	0.50	0.52	0.52	0.04	0.026	0.494	0.45	0.60	1.00	0.133	220.00	0.01	56260.00	1759771.49	40000.00	1719771.49		
2011	1.00	0.50	0.52	0.52	0.04	0.026	0.494	0.45	0.60	1.00	0.133	220.00	0.01	56260.00	1759771.49	40000.00	1719771.49		
2012	1.00	0.50	0.52	0.52	0.04	0.026	0.494	0.45	0.60	1.00	0.133	220.00	0.01	56260.00	1759771.49	40000.00	1719771.49		
2013	1.00	0.50	0.52	0.52	0.04	0.026	0.494	0.45	0.60	1.00	0.133	220.00	0.01	56260.00	1759771.49		1759771.49		
2014	1.00	0.50	0.52	0.52	0.04	0.026	0.494	0.45	0.60	1.00	0.133	220.00	0.01	56260.00	1759771.49		1759771.49		
2015	1.00	0.50	0.52	0.52	0.04	0.026	0.494	0.45	0.60	1.00	0.133	220.00	0.01	56260.00	1759771.49		1759771.49		
2016	1.00	0.50	0.52	0.52	0.04	0.026	0.494	0.45	0.60	1.00	0.133	220.00	0.01	56260.00	1759771.49		1759771.49		
2017	1.00	0.50	0.52	0.52	0.04	0.026	0.494	0.45	0.60	1.00	0.133	220.00	0.01	56260.00	1759771.49		1759771.49		
2018	1.00	0.50	0.52	0.52	0.04	0.026	0.494	0.45	0.60	1.00	0.133	220.00	0.01	56260.00	1759771.49		1759771.49		
2019	1.00	0.50	0.52	0.52	0.04	0.026	0.494	0.45	0.60	1.00	0.133	220.00	0.01	56260.00	1759771.49		1759771.49		
2020	1.00	0.50	0.52	0.52	0.04	0.026	0.494	0.45	0.60	1.00	0.133	220.00	0.01	56260.00	1759771.49		1759771.49		
															1456533.07				

E6: Open economy: Economic surplus results for Virus-tolerant tomato varieties in Mali

YEAR	e	n	YIELD CHANGE	GROSS PROPOR. COST CHANGE	PROPOR. I. COST CHANGE PER HA.	PROPOR. I. COST CHANGE PER TON	NET CHANGE	PROB OF SUCCESS	ADOPT RATE	Depre Rate	K	PRICE	EXOGEN. OUTPUT CHANGE	QUANTITY	CTS	COST	BENEFIT	NPV	NPV2
2003	1.00	0.50	0.11	0.11	0.02	0.018	0.092	0.44	0.00	1.00	0.000	220.00	0.01	68703.00	0.00	50000.00	-50000.00		
2004	1.00	0.50	0.11	0.11	0.02	0.018	0.092	0.44	0.12	1.00	0.005	220.00	0.01	68703.00	73584.85	50000.00	23584.85		
2005	1.00	0.50	0.11	0.11	0.02	0.018	0.092	0.44	0.24	1.00	0.010	220.00	0.01	68703.00	147526.21	50000.00	97526.21		
2006	1.00	0.50	0.11	0.11	0.02	0.018	0.092	0.44	0.36	1.00	0.015	220.00	0.01	68703.00	221824.07	50000.00	171824.07		
2007	1.00	0.50	0.11	0.11	0.02	0.018	0.092	0.44	0.45	1.00	0.018	220.00	0.01	68703.00	277781.44	50000.00	227781.44	2942442.30	3328529.05
2008	1.00	0.50	0.11	0.11	0.02	0.018	0.092	0.44	0.60	1.00	0.024	220.00	0.01	68703.00	371489.34	50000.00	321489.34		
2009	1.00	0.50	0.11	0.11	0.02	0.018	0.092	0.44	0.60	1.00	0.024	220.00	0.01	68703.00	371489.34	50000.00	321489.34		
2010	1.00	0.50	0.11	0.11	0.02	0.018	0.092	0.44	0.60	1.00	0.024	220.00	0.01	68703.00	371489.34	50000.00	321489.34		
2011	1.00	0.50	0.11	0.11	0.02	0.018	0.092	0.44	0.60	1.00	0.024	220.00	0.01	68703.00	371489.34	50000.00	321489.34		
2012	1.00	0.50	0.11	0.11	0.02	0.018	0.092	0.44	0.60	1.00	0.024	220.00	0.01	68703.00	371489.34	50000.00	321489.34		
2013	1.00	0.50	0.11	0.11	0.02	0.018	0.092	0.44	0.60	1.00	0.024	220.00	0.01	68703.00	371489.34		371489.34		
2014	1.00	0.50	0.11	0.11	0.02	0.018	0.092	0.44	0.60	1.00	0.024	220.00	0.01	68703.00	371489.34		371489.34		
2015	1.00	0.50	0.11	0.11	0.02	0.018	0.092	0.44	0.60	1.00	0.024	220.00	0.01	68703.00	371489.34		371489.34		
2016	1.00	0.50	0.11	0.11	0.02	0.018	0.092	0.44	0.60	1.00	0.024	220.00	0.01	68703.00	371489.34		371489.34		
2017	1.00	0.50	0.11	0.11	0.02	0.018	0.092	0.44	0.60	1.00	0.024	220.00	0.01	68703.00	371489.34		371489.34		
2018	1.00	0.50	0.11	0.11	0.02	0.018	0.092	0.44	0.60	1.00	0.024	220.00	0.01	68703.00	371489.34		371489.34		
2019	1.00	0.50	0.11	0.11	0.02	0.018	0.092	0.44	0.60	1.00	0.024	220.00	0.01	68703.00	371489.34		371489.34		
2020	1.00	0.50	0.11	0.11	0.02	0.018	0.092	0.44	0.60	1.00	0.024	220.00	0.01	68703.00	371489.34		371489.34		
															308337.67				

Table H: Open economy: Economic surplus results for overall IPM technologies (Virus-tolerant tomato varieties and Host-free period)

YEAR	e	n	YIELD CHANGE	GROSS PROPOR. COST CHANGE	PROPOR. I. COST CHANGE PER HA.	PROPOR. I. COST CHANGE PER TON	NET CHANGE	PROB OF SUCCESS	ADOPT RATE	Depre Rate	K	PRICE	EXOGEN. OUTPUT CHANGE	QUANTITY	CTS	COST	BENEFIT	NPV	NPV2
2003	1.00	0.50	0.63	0.63	0.06	0.037	0.593	0.45	0.00	1.00	0.000	220.00	0.01	68703.00	0.00	90000.00	-90000.00		
2004	1.00	0.50	0.63	0.63	0.02	0.012	0.618	0.45	0.12	1.00	0.033	220.00	0.01	68703.00	512595.29	90000.00	422595.29		
2005	1.00	0.50	0.63	0.63	0.02	0.012	0.618	0.45	0.24	1.00	0.067	220.00	0.01	68703.00	1042008.92	90000.00	952008.92		
2006	1.00	0.50	0.63	0.63	0.02	0.012	0.618	0.45	0.36	1.00	0.100	220.00	0.01	68703.00	1588240.91	90000.00	1498240.91		
2007	1.00	0.50	0.63	0.63	0.02	0.012	0.618	0.45	0.45	1.00	0.125	220.00	0.01	68703.00	2008951.94	90000.00	1918951.94	**23652463.65**	**24347419.80**
2008	1.00	0.50	0.63	0.63	0.02	0.012	0.618	0.45	0.60	1.00	0.167	220.00	0.01	68703.00	2731159.93	90000.00	2641159.93		
2009	1.00	0.50	0.63	0.63	0.02	0.012	0.618	0.45	0.60	1.00	0.167	220.00	0.01	68703.00	2731159.93	90000.00	2641159.93		
2010	1.00	0.50	0.63	0.63	0.02	0.012	0.618	0.45	0.60	1.00	0.167	220.00	0.01	68703.00	2731159.93	90000.00	2641159.93		
2011	1.00	0.50	0.63	0.63	0.02	0.012	0.618	0.45	0.60	1.00	0.167	220.00	0.01	68703.00	2731159.93	90000.00	2641159.93		
2012	1.00	0.50	0.63	0.63	0.02	0.012	0.618	0.45	0.60	1.00	0.167	220.00	0.01	68703.00	2731159.93	90000.00	2641159.93		
2013	1.00	0.50	0.63	0.63	0.02	0.012	0.618	0.45	0.60	1.00	0.167	220.00	0.01	68703.00	2731159.93		2731159.93		
2014	1.00	0.50	0.63	0.63	0.02	0.012	0.618	0.45	0.60	1.00	0.167	220.00	0.01	68703.00	2731159.93		2731159.93		
2015	1.00	0.50	0.63	0.63	0.02	0.012	0.618	0.45	0.60	1.00	0.167	220.00	0.01	68703.00	2731159.93		2731159.93		
2016	1.00	0.50	0.63	0.63	0.02	0.012	0.618	0.45	0.60	1.00	0.167	220.00	0.01	68703.00	2731159.93		2731159.93		
2017	1.00	0.50	0.63	0.63	0.02	0.012	0.618	0.45	0.60	1.00	0.167	220.00	0.01	68703.00	2731159.93		2731159.93		
2018	1.00	0.50	0.63	0.63	0.02	0.012	0.618	0.45	0.60	1.00	0.167	220.00	0.01	68703.00	2731159.93		2731159.93		
2019	1.00	0.50	0.63	0.63	0.02	0.012	0.618	0.45	0.60	1.00	0.167	220.00	0.01	68703.00	2731159.93		2731159.93		
2020	1.00	0.50	0.63	0.63	0.02	0.012	0.618	0.45	0.60	1.00	0.167	220.00	0.01	68703.00	2731159.93		2731159.93		
															2258715.34				