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Ex-ante Economic Analysis of Biological Control of Coconut Mite in Benin

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The coconut mite, *Aceria guerreronis* Keifer, has been identified as one of the pests that pose a threat to the coconut industry in Benin using a standard economic surplus model. The study presents the simulation results of the economic benefits of the biological control of coconut mites in Benin. In the least optimistic scenario, the economy would derive an overall net-gain of US$155,213.40. Considered at a discount rate of 12% for the period 2008-2027, net present value was about US$207,721, while the internal rates of return or break-even discount rates are high at 13.21%. It is therefore recommended that contemporaneous with the release of natural predators of the coconut mite, plans should be underway for improving research and extension services to coconut farmers in Benin.

Key words: *Aceria guerreronis*, biological control, Benin, ex-ante economics, Tanzania.

Introduction

Coconut (*Cocos nucifera* Beccari) is the main source of cash income for farmers in the coastal belt of Benin. Oleke, Manyong, Hanna, and Isinika (2010) reported that coconut contributes about 56% of the total head of household cash income among coconut farmers in Benin, equivalent to US$400[1] of the total rural household cash income. Additionally, coconut juice serves as an important supply of fluids and minerals. The oilcake remaining after oil is pressed from copra is used as animal feed (Woodroof, 1970). The coconut shell is used directly as fuel, filler, and extender in the synthesis of plastic and for making household articles. In the coastal belt of Benin, different parts of the coconut plant (truck and leaves) are widely used as building materials, and in recent years the coconut palm wood has been used to make high-quality furniture for the local and export market.

The coconut, like many plants, is subject to attack by various pests and diseases. The coconut mite, *Aceria guerreronis* Keifer, has been identified among common coconut pests of economic importance. The coconut mite breeds under the perianth (the outer part of the flower consisting of the calyx and corolla, and enclosing the stamen and pistils) of coconuts, where it feeds on the epidermal cells of the meristematic region. Occasionally it feeds on the apical meristem of the coconut seedling. In severe infestations, reduction in nut size and malformation of nuts occur. Consequently, farmers incur economic losses due to the continued presence of pest. The coconut mite is therefore one of the leading exotic pests that pose a threat to the coconut industry in countries such as Benin, Tanzania, India, and Sri Lanka. The coconut mite has proven to be difficult to control. A wide range of chemicals have been employed to control the pest over the past two decades, but the results have been unsatisfactory. Thus, efforts to eradicate it or minimize its damage have been expensive (Pimentel, 2000). Meanwhile, farmers continue to suffer high economic loss (Aquino & Arruda, 1967). Good plant husbandry has been recommended to alleviate the economic impact of the mite on coconut production. In the mean time, research has been directed toward identifying resistant coconut varieties and biological control agents (Pimentel, 2000).

Decreases in coconut yield from mite attack cause loss of income, food insecurity, and poverty for farmers and others in the coconut value chain. A survey was carried out by the Coconut Research Institute (CRI) in Sri Lanka in 2001 to monitor harvested nuts for one year at monthly intervals. The study revealed that the percentage of mite-infested nuts in various Sri Lankan cities was 94.4% in Anuradhapura, 94.5% in Pollonnaruwa, 90.5% in Rajangane, 85.1% in Puttalam, and 69.8% in Kurunegala, with a mean of 77.9% (Peiris, 2006). In Tanzania, reduction in copra yield has been variable from 15-40% (Seguni, 2002). Elsewhere, losses due to extensive premature dropping of fruits have been reported, ranging from 60% in Colombia (Zuluaga & Sánchez, 1971) to 70% in Venezuela (Doreste, 1968) and 10-100% (average 21%) in Tanzania (Seguni, 2002). For the nuts that reach maturity, small-sized nuts

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[1] *Unless otherwise specified, all monetary values in the article are in US dollars.*

cannot be sold at the price of a full size nut, thus reducing the income of the farmer since they fetch lower prices. Peiris (2006) estimated loss of income for coconut growers in Sri Lanka to be 7% from rejected nuts and 43% from small-sized nuts. In Tanzania, loss of farmers' income due to coconut mite is estimated to be about 30-50% (Seguni, 2002). Oleke et al. (2010) similarly reported that coconut production at the household level in Tanzania had declined by about 52% since 2007 largely due to attack by coconut mite.

In order to address the problem of declining production due to coconut mite in Benin, the International Institute of Tropical Agriculture (IITA), in collaboration with University of Amsterdam, has been considering biological control of the coconut mite in order to enhance coconut productivity and profitability in affected countries of Africa. Benin was chosen due to the economic importance of the crop for the livelihood of farmers who depend on it. The identified invasive predators (*Neoseiulus baraki*, *N. paspalivorus*, and *Proctolaelaps bickleyi*) are biologically more efficient in reducing coconut mite populations, as shown from areas that have been explored in Brazil (WOTRO Science for Global Development, 2007).

Economic analyses of biological control programs are a valuable input into the decision-making process for biological control programs. Assessing the impact of agricultural research can assist in providing feedback to the research programs and demonstrating actual benefits of the products of research. The basic criterion is that a biological control program should be considered when the benefits are greater than the costs (Jetter, 2005). However, assessing all costs and benefits to a biological control program presents a challenge due to the different analysis methods. Using the economic surplus approach, this study analyzed the likely costs and benefits of implemeting biological control of the coconut mite in Benin. The specific objective of this study was to estimate the total economic surplus derived from introducing biological control of coconut mite and the distribution of such benefits amongst producers and consumers.

Many studies have indicated the economic benefits of investing in biological control. Two studies—one by Norgaard (1988) and another by Zeddies, Schaab, Neuenschwander, and Herren (2000)—demonstrated the high returns of biological control of cassava mealy bug in Africa. Coulibaly et al. (2004) applied an economic surplus model to assess the economic benefits of the classic control of cassava green mite in West Africa. De Groote, Ajuono, Attignon, Djessou, and Neuenschwander (2003) calculated the economic impact of biological control of water hyacinth in Southern Benin. In Benin, Bokonon-Ganta, De Groote, and Neuenschwander (2002) studied the economic impact of the biological control of mango mealy bug through a survey of mango producers. Alene, Neuenschwander, Manyong, Coulibaly, and Hanna (2006) provided an excellent summary of past economic studies on biological control of major pests in sub-Saharan Africa. While many studies have been carried out on the economic impact of biological control, no specific study has been done on coconut mite in Benin, a gap that this article addresses. The economic surplus approach is a powerful tool to estimate the potential benefits of an agricultural and development program, such as the biological control program of coconut mite.

Norton, Ganoza, and Pomareda (1987) employed an ex-ante economic surplus framework to analyze the potential benefits of agricultural research and extension (R&E) in Peru. The study's projected rates of return to R&E in Peru point to large returns to public investment. Variations in R&E benefits across crops bring to the forefront the issues related to allocation of resources.

Krishna and Qaim (2007) studied the potential impacts of Bt eggplant on the economic surplus and health of people in India. Comprehensive farm survey data were used to project farm-level effects and future adoption rates. Simulations showed that the aggregate economic surplus gains of Bt hybrids could be around $108 million per year. Meanwhile, Bayer, Norton, and Falck-Zepeda (2010) evaluated the economic impact of the regulatory process on four transgenic crops in the Philippines: Bacillus thuringiensis (Bt) rice, ringspot virus-resistant (PRSV) papaya, Bt eggplant, and multiple virus-resistant (MVR) tomato. With Bt eggplant and MVR tomato, the Philippines is modeled as a small closed economy; however, when dealing with Bt rice and PRSV papaya, the country is considered a small open economy. The net benefits (total surplus less total costs) are substantial—$20.5 million for Bt eggplant, $33.5 for MVR tomato, $257.2 for Bt rice, and $240.2 for PRSV papaya.

In their study, Islam and Norton (2007) assessed the potential economic impacts of transgenic salinity- and drought-resistant (SDR) rice in Bangladesh. The ex-ante analysis projected that planting SDR rice over 10 years has a total economic surplus amounting to $302.8 million if no international trade is assumed, of which $184.1 million is producer surplus (PS) and $119.7 million is consumer surplus (CS). The net present value (NPV) of benefits is $215.7 million and the internal rate of return (IRR) is 33.8%. Hareau, Mills, and Norton (2006) conducted an ex-ante evaluation of the economic impact of herbicide-resistant transgenic rice in Uruguay, accounting for multinational market power. They came up with a $1.82 million mean NPV for producers, while $0.55 million will go to the multinational firm.

Theoretical Framework

In analyzing net benefits from biological control programs, different approaches are used. Such considerations include reversible and irreversible benefits, as well as costs the technology will generate. Kikulwe, Wesseler, and Falck-Zepeda (2008) defined reversible costs and benefits as those that can be reversed after the planting of the crop and do not result in additional ex-post (after stopping production) costs and benefits. On the other hand, irreversible costs and benefits refer to those that will continue to occur even if coconuts are no longer produced or those that cannot be fully reversed. The authors further assert that the reversible and irreversible costs and benefits can be further differentiated into private and non-private costs and benefits. This differentiation is useful for understanding the distribution of costs and benefits between, for example, farmers (private) and society at large (non private). It is argued by Kikulwe et al. (2008) that the concept of uncertainty and irreversibility has found wide application in decision-making among economists and has a tradition in environmental economics that originated in the early 1970s with papers published by Arrow and Fisher (1974) and Henry (1974); in economics it can even be traced back to Louis Bachelier (1900; Bernstein, 1992). While irreversible costs have their relevance for decision-making, this study utilizes the consumer-surplus approach suggested by Alston, Norton, and Pardey (1995). In the concept of uncertainty and irreversibility, commonly found trigger values are up to 2 and even under such a high trigger value the project would generate a positive value (Wesseler, 2009).

The analysis of economic benefits uses the concepts of supply and demand in partial equilibrium. The economic surplus analysis builds upon the approach first utilized by Griliches (1957) in his pioneering study on hybrid corn in which adoption of a technological innovation fosters a downward shift in the supply curve through reductions in the unit cost of production. From economic theory, a supply function can be derived from production cost data. The supply function is not only affected by price or quantity, but also by any factor that could modify the costs of production and shift the supply curve. Adopting a new technology can therefore have a shifting effect on the supply curve. Economic surplus analysis considers the nature of the market for the commodity and the fact that prices may fall as production changes and supply increases. In conducting economic surplus analysis, market effects stemming from whether the product is widely traded are considered. The consumer surplus models can be used both as closed and open economy models. Closed models are used for the commodities that are produced and consumed within the country. In open economy models—such as that of coconut—commodities are linked to international markets. In Benin, where coconuts are exported to neighbouring countries like Nigeria and Togo, we consider a small open economic model.

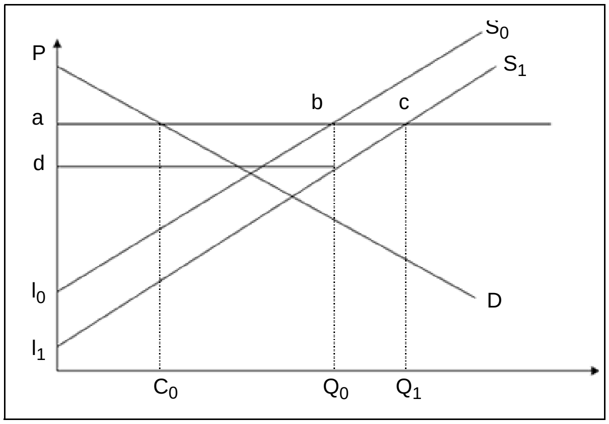

Figure 1. Induced supply shift (small open economy).

With a small open economy, the main assumption in a country such as Benin is that it is “too small” in the world-market trade of coconut products to influence the international price significantly (Figure 1). The world price remains constant and all the benefits of the supply shift accrue to producers. The increased coconut production will shift the supply curve downward from S_0 to S_1, and the domestic demand curve of papayas is assumed to remain unchanged. Consumer surplus thus remains constant, whereas producer surplus increases equal to the area l_0bcl_1.

Estimating Consumer, Producer, and Total Surplus

From the preceding discussion, with the introduction of biological control and the subsequent outward shift of the supply curve, the technology-induced change can be treated as an intercept change (a shift factor *k*) in the supply curve along with the respective quantity supplied and quantity demanded. Following Alston et al. (1995),

Table 1. Actual research cost.

		Year 1	Year 2	Year 3	Year 4	Total
Total cost (€)[1]		36,430.00	31,290.00	25,640.00	29,930.00	123,290.00
Total cost (US$)		52,714.21	45,276.63	37,101.08	43,099.20	178,191.10
		Follow up costs				
Budget line/item	**Source**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Total**
Personnel, in-kind	Applicants	12	12	12	12	48
Personnel, in-kind	Collaborators	10	10	10	10	40
Laboratory	University of Amsterdam, IITA, National Research Systems	10	10	10	10	40
Total	-	32	32	32	32	128

[1] *Exchange rate €1=$1.44; Source: WOTRO (2007)*

the absolute relative reduction in price is measured by Z. Changes in producer, consumer, and total surplus are estimated by these parameters, K and Z and are calculated as

$$K = \{[(\mu - \alpha) - P_0(\beta + \mu)] / \beta\}\, p_s \text{ and} \tag{1}$$

$$Z = [(P_1 - P_0)/P_1] = -\,[K\varepsilon_s / (\varepsilon + \eta)]. \tag{2}$$

In each year, the downward shift of the supply curve due to technology-induced cost saving from the initial market equilibrium price before the supply shift is P_0 , while P_1 represents the new equilibrium price due to increased coconut production; ε_s and η are the supply and demand elasticizes, respectively; μ is the intercept of the demand curve; α and β are the slope of the demand and supply curves, respectively; and p_s is the probability of research success. The changes in producer, consumer, and total surplus in the closed economy are given by

$$\Delta CS = P_0Q_0Z(1 + 0.5Z\eta)\ , \tag{3}$$

$$\Delta PS = P_0Q_0\,(K - Z)\,(1 + 0.5z\eta)\ , \text{ and} \tag{4}$$

$$\Delta TS = \Delta CS + \Delta PS = P_0Q_0K(1 + 0.5Z\eta)\ . \tag{5}$$

In case of the small open economy model, the formulae for estimating changes in producer, consumer, and total surplus are given by

$$\Delta SC = 0 \text{ and} \tag{6}$$

$$\begin{aligned} \Delta PS = \Delta TS &= P_wQ_0K(1 + 0.5K\varepsilon_s) \\ &= P_0Q_0K(1 + 0.5K\varepsilon_s)\ , \end{aligned} \tag{7}$$

where ΔCS is the change in consumer surplus, ΔPS is the change in producer surplus, ΔTS is the change in total surplus, ε_s is the elasticity of supply, η is the elasticity of demand, P_0 is the pre-innovation price, Q_0 is the pre-innovation quantity produced, P_w is the world price, while Z and K are as previously defined.

Methodology

The simulation of benefits of biological control of coconut was done using Dynamic Research Evaluation for Management (DREAM) software developed for the International Food Policy Research Institute (IFPRI) by Wood, You, and Baitx (2001). The software calculates and analyzes the benefits derived from technological change, which are measured as economic surplus of producers and consumers. The model also estimates indicators of social gains from investment in research. By introducing into the model the annual flows of investments in research and development, indicators of social gains such as the NPV, IRR, and the cost/benefit (C/B) ratio were estimated.

Empirical Models, Data, and Assumptions

For this study the baseline levels of production were gathered from an agricultural research station in Semi Podjin, Benin. Coconut yields were estimated at 25,000 tons during the 2008/2009 season. The farm-level price of coconut in Benin was estimates at $45 per ton. Table 1 presents research costs over time for biological control of coconut mites. Table 2 summarizes parameters assumed in each scenario. It is not possible to assess the impact of research without data on the technology it produces. It is assumed that there is no cost savings since most current farmers do not use either pesticides or herbicides. In addition, the costs of biological control are assumed to be the same because there is no anticipated technology fee charged by the governments in the

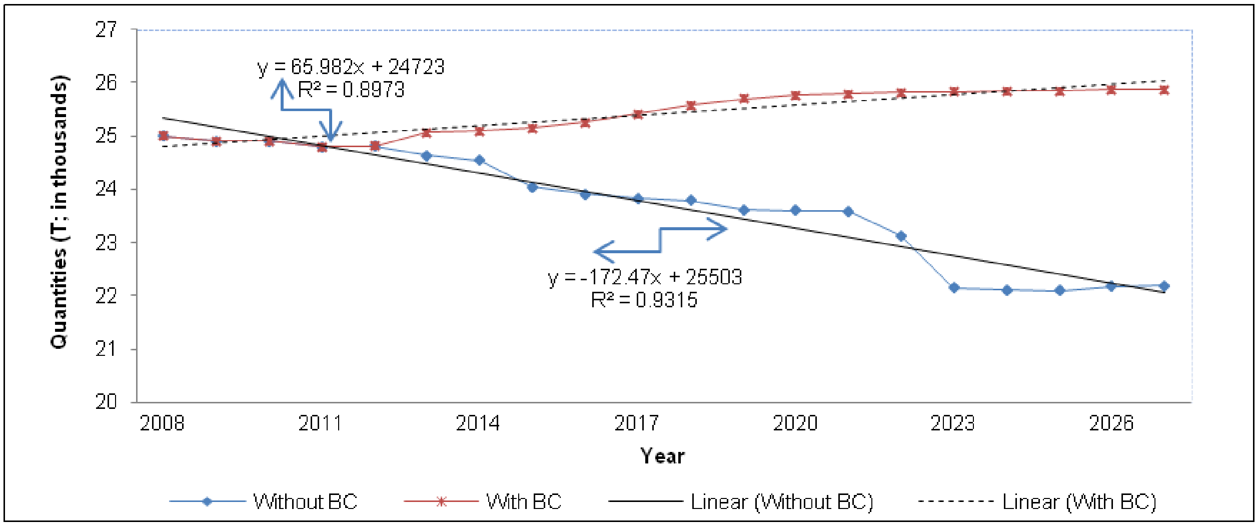

Figure 2. Equilibrium quantities due to biological control of coconut mites.

Table 2. Sources of some of parameters used.

Variable	Data/ parameter	Source of data
Production quantity, (Q_0) (ton)/year	23,121	Semi Podji research station, Benin
Annual production area growth (%)	0.04	Semi Podji research station, Benin
Yield in the start of period of simulation (tons)	25,000	Semi Podji research station, Benin
Price, P_o (\$/ton)	45	Food and Agricultural Organization of the United Nations (2010)
Export volume, (Q_o– C_o) (ton)	8,140	Semi Podji research station, Benin
Consumption quantity, C_o (ton) / country (2008)	14,981	Semi Podji research station, Benin
% yield increase, Δ(Y)	50	Interviews with scientists (WOTRO, 2007)
% cost reduction, E(C)	0	-
Elasticity of supply (η)	0.4	Ackah and Appleton (2007)
Elasticity of demand (ε)	-0.552	Ackah and Appleton (2007)
Maximum adoption rate (%)	90	Interviews with scientists (WOTRO, 2007)
Lag of R&D returns after first adoption (years)	6	Interviews with scientists (WOTRO, 2007)
Simulation period (years)	20	Interviews with scientists (WOTRO, 2007)

two countries. The discount rate is varied and compared within 12% to 20%.

As the technology for biological control of coconut mites using natural predators is still in the development stage, reliable farm-level estimates of changes in yield from its spread could not be obtained. Based on scientist interviews, the probability of success has been set at 90%. Hence, in this study, the full impact of biological control is expected to be a 50% increase of the base scenario in Benin. These estimates are based on responses from scientists from the research program who are involved in collecting predators. The scientist respondents defined the probability of research success as the likelihood that the biological agents will be successfully identified, bred, and released and they in turn successfully suppress the coconut mite. Scientists agreed that the required predator has been identified with complete certainty and multiplied ready for release. It may take time for the biological control agent to completely spread throughout the area infested with coconut mites. Pickett et al. (1996) showed that some agents spread very quickly while others spread at a much slower rate. For simplicity, in this study we assumed that if the program is successful—after introducing the biological control agent—it will take 6 to 10 years to spread throughout the entire mite-infested area, which also marks the end of the program.

If the homogeneity condition holds, the price elasticity for a normal good is in many cases slightly higher than the income elasticity with an opposite sign. The homogeneity condition states that the sum of income elasticity of demand, own-price elasticity of demand,

Table 3. Total benefit.

Year	Producer surplus	Consumer surplus	Total benefits	Total cost	Benefits − cost
2008	0	0	0	-52,714.21	-52,714.21
2009	0	0	0	-45,276.63	-45,276.63
2010	0	0	0	-37,101.08	-37,101.08
2011	0	0	0	-43,099.20	-43,099.20
2012	0	0	0	0	0
2013	1,537.6	0	1,537.6	0	1,537.50
2014	3,831.0	0	3,831.0	0	3,831.00
2015	9,136.8	0	9,136.8	0	9,136.70
2016	19,827.5	0	19,827.5	0	19,827.40
2017	36,418.7	0	36,418.7	0	36,418.70
2018	54,022.8	0	54,022.8	0	54,022.70
2019	66,558.6	0	66,558.6	0	66,558.50
2020	73,184.8	0	73,184.8	0	54,022.70
2021	76,153.7	0	76,153.7	0	66,558.70
2022	77,394.4	0	77,394.4	0	73,184.80
2023	77,425.3	0	77,425.3	0	76,153.60
2024	77,426.3	0	77,426.3	0	77,456.30
2025	77,487.3	0	77,487.3	0	77,487.20
2026	77,518.3	0	77,518.3	0	77,518.20
2027	77,549.3	0	77,549.3	0	77,549.20
Discounted totals[1]	**155,213.4**	**0**	**155,213.4**	**1.01**	**153,393.60**

[1] DREAM software computes total costs and benefits discounted over the entire period of simulation. These totals are not simple additions and averages.

and cross-price elasticities equals 0 (Alston et al., 1995). In Benin, Ackah and Appleton (2007) estimated the elasticity of similar products (palm oil and groundnut) to be -0.552. We use the same base-price elasticity for Benin. Rao (1989) estimated the agricultural supply response to prices in developing countries and found crop-specific acreage elasticities varied from 0 to 0.8 in the short-run and from 0.3 to 1.2 in the long-run for a wide variety of crops. Since no estimates for supply elasticity of coconut and related crops are available for Benin, we use the elasticity estimated in Benin by Ackah and Appleton (2007) for similar commodities—0.4.

Simulated Equilibrium Quantities

Figure 2 shows the simulated supply and demand equilibrium points of the quantities of coconut produced and traded over the period of 20 years. In a small open model (Benin), it is assumed that coconut production will remain constant during the first five years and begin to increase as the effect of predators begins and continues to be felt. While the simulation model shows that production will remain constant (when interest rate ‘r’ and probability of success ‘p’ are 12% and 90%, respectively), there may also be some decline in production over the period of five years due to other factors that are not exclusive of coconut-mite attack. The first five years are designed for technology development and, hence, no increase in coconut production is expected. As shown in Figure 2, the benefits from research, in terms of increased production, grow slowly at first. Over the entire period of simulation, analysis of time against yield (tonnes) shows that in Benin yield will increase by about 65.09 tons per year (R^2=89.7%). Meanwhile, production without biological control shows a decrease in yield by 172 tons per year (R^2=93%).

As shown in Table 3, the research cost is highest before and after the technology is released. At this point, the net benefits (benefits minus costs) do not become positive until spread of biological control is well underway. In the cases shown, the gains increase as the technology continues to spread to a larger part of the affected area. Since Benin is a small exporting economy, the changes in prices due to biological control will not affect the regional markets prevailing in West Africa. Thus, the changes in prices and the corresponding

Table 4. Sensitivity analysis in relation to the discount rate.

Discount rate	Producer surplus	Consumer surplus	Total economic surplus	Total cost	(Benefits − cost)	(C/B)	IRR
12%	155,213.3	0	155,213.3	1,533,393.30	1,819	1.01	13.21
15%	107,869.1	0	107,869.1	148,477.36	-4,608	0.73	13.21
18%	76,225.6	0	76,225.6	143,961.16	-67,735	0.53	13.21
20%	61,002.8	0	61,002.8	141,151.04	-80,148	0.43	13.21

changes in consumer surplus are equal to 0. However, consumers may still benefit from improved quality and continuity of coconut supply.

The surplus resulting from agricultural research expenditures was positive and substantial every year in the period considered for simulation. The producers captured the benefit of about $155,213.40 (100%) of total benefits resulting from the investment. These findings are also consistent with those reported by Bayer et al. (2010) that there was no change in consumer surplus due to the use of a small open economy assumption in the study of the cost of compliance with biotechnology regulation on PRSV papaya and Bt rice in the Philippines. Another study by Napasintuwong and Traxler (2009) on an ex-ante impact assessment of GM papaya adoption in Thailand also reported zero change in consumer surplus when a small open model was considered.

Sensitivity Analysis

In the analysis, some of the parameters—including the discount rate and the probability of research success—are uncertain because precise information for a future period is lacking. In order to determine the robustness of the simulated returns (net benefits, C/B, and IRR) in view of such uncertainty, these parameters have been varied to check the corresponding changes in the benefits accruing to producers and consumers. The effects of discount-rate changes on returns to investment were estimated by increasing the discount rate from 12% to 20%, commonly used in long-term projects (15-20 years) in developing countries. High discount rates discourage investments with long-term benefits spread over a long period, which include research such as this study.

As shown in Table 4, the total discounted value of economic surplus is $155,213.40 at a discount rate of 12%. If the discounting rate is raised to 15% economic surplus drops to $107,869.10, while the IRR remains the same (13.21%). When a discount rate of 20% is used, it causes further drop in economic surplus to $61,002.80. This means the higher the discount rate, the smaller the gain from the research project. As it is for net benefit, the sensitivity analysis results show that the higher the ple, when the discount rate is 12%, the C/B ratio is 1.01, whereas a 20% discount rate results in a cost benefit of 0.43.

Table 5. NPV for different probability of success.

Probability of success	NPV	Change in NPV	% change	IRR (%)
20%	34,192	-	-	-0.05
40%	68,556	34,364	100	5.69
60%	103,090	34,534	50	9.32
80%	145,789	42,699	41	12.06
100%	172,673	26,884	18	14.13

A discount rate of 12% was assumed for computing the IRR, as presented in Table 4. Results show that as the probability of research success increases, the IRR also increases. Furthermore, since one of the criteria to establish the worthiness of the project is IRR, these findings indicate that in order for this project to be beneficial it should be successful by more than 80%.

The NPV of the investment was similarly subjected to sensitivity analysis upon changing the probability of success (Table 5). Again, the probability of success was varied from 20% to 100%. When the probability is assumed to be 20%, NPV reached $34,192. When the probability of research success is increased to 40%, the NPV increases by 100%. Furthermore, if 60% and 80% probability of success were considered, the resulting NPV increased by 50% and 41%, respectively; this implies that as the probability of success increases, the NVP increases at a decreasing rate in both countries. Results in Table 5 show that even if coconut mites are controlled by 40% (which is lower than half of our baseline assumption of 90% probability of research success) the investment will still produce positive net benefit.

Sensitivity analysis was also done for the NPV in relation to the discount rate as summarized in Table 6. The percentage decline in NPV when the discount rate is reduced from 20% to 12% is about 61%. Decreasing the discount rate from 15% to 12% causes a 30% increase in NPV. Decreasing the discount rate further increases the NPV even more. These results clearly demonstrate that even if the interest rate is set much higher than the base case (12%), the NPV still will be

Table 6. NPV and varying discount rate.

Discount rate	NPV	Change in NPV (US$)	% change
12%	207,721	-	-
15%	144,349	-63,372	-30
18%	101,996	-42,353	-29
20%	81,622	-20,374	-19

positive, indicating that the investment for biological control of coconut mites is economically viable.

Conclusion and Implications

These findings provide consistent evidence to confirm our working hypothesis that biological control of the coconut mite is a viable technology. Sensitivity analysis shows that the results remain robust even when the discount rate is raised up to 20%, which is higher than that of the market rate. Similarly, the investment remains viable even when the probability research is reduced to 80%, at which point the IRR is 12.06%, which is equal to the accepted discount. The results also suggest a positive relationship between program effectiveness (measured in terms of NPV) and net-gains (expressed as producer and consumer surplus). In the least optimistic scenario, the economy in Benin is expected to have a net gain of $155,213.40. On the basis of these results, the study concludes that there is strong evidence that economic returns from investing in this research to control coconut mite are highly significant from zero, and they can withstand wide variation of key variables, including the discount rate and the probability of research success.

Since the natural ecosystem is dynamic and constantly changing, expected benefits can only be maintained if other negative factors that may arise to undermine the positive impacts of this technology will be addressed through well-planned, financed, and evaluated extension services. It is recommended that contemporaneous with the release of natural predators of the coconut mite, plans should be underway for improving research and extension services to coconut farmers in Benin. This technology has proved to be economically viable even when key variables such as the discount rate and the probability of research success are varied over a wide range. It is further recommended that plans should be made to use this technology in other countries such as Ghana, Côte d'Ivoire, and Nigeria, which have suffered considerable loss of coconuts due to coconut mites.

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