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A New Biopesticide for the Control of Fruit Flies in Organic Mango Production: An Ex-Ante Assessment of Returns to Research Using Economic Surplus Model

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Abstract

Nowadays, several technical and financial partners are reluctant to support agricultural research because they don't perceive its impact. So, to gain the support of local authorities and decision-makers, research scientists must bring evidence of its financial viability. Fruit flies are a major constraint to increasing mango productivity in Africa. However, there are other challenges as well. Research scientists have investigated several methods to control fruit flies. This study aims to evaluate the potential economic impact of developing a new biopesticide to control mango fruit flies in Burkina Faso. This concept's main idea is that the adoption of this new technology would result in higher yields and cheaper production costs. The economic surplus model is the methodology applied in this assessment. This concept's main idea is that implementing better technology lowers production costs while increasing yield. According to the mango research findings, the net present value is calculated to be 76,740,608 US$, either 46,428,067,840 FCFA, while the social gain is estimated to be 76,836,954 US$, either 46,486,357,170 FCFA. This investment yielded an estimated internal rate of return of 190.54%, which is significantly higher than the interest rates that banks charge. Mango production would benefit from the research, notwithstanding the scarce resources. These findings imply that funding research on the new biopesticide would be a fascinating and financially feasible substitute for governmental bodies. If research on bodies could benefit from more funding or financial independence, the benefits of developing new biopesticides would be amplified.

Keywords

Ex-Ante Impact, Research, Biopesticide, Economic Surplus, Organic Mango

1. Introduction

Mango production plays a major socio-economic and environmental role in Burkina Faso. In fact, mango production accounts for 62.5% of the country's total fruit production, making it the leading fruit crop (18% of West African production) (Parrot et al., 2017). Small farmers with limited capital produce more than 90% of mango total production (Vayssières et al., 2008). The mango industry employs approximately 64,000 persons (growers, processors, traders, exporters, trackers, etc.) in Burkina Faso (APROMAB, 2021). Mango is the main exported from the Burkina Faso (Ouédraogo, 2011). Furthermore, Burkina Faso is the leading country in the West Africa sub-region in the exportation of dried mangoes, capitalizing on a unique market niche: fair-trade and organic markets (Ouédraogo, 2011). In addition to these benefits, the mango industry contributes to food and nutritional security, particularly for the most marginalized and vulnerable persons. The mango industry has become a promising and priority sector in the nation's development policies and strategies because of all these advantages (SP/CPSA, 2018).

Despite these advantages, biotic and abiotic constraints impede the growth of the mango industry. The most important biotic constraints are diseases and insect pests. Fruit flies are the top insect pests associated with mango in Burkina Faso. Mango is primarily threatened by fruit flies, specifically those belonging to the genera *Bactrocera dorsalis* and *Ceratis cosyra* (Zida et al., 2023). Fruit fly damage results in the loss of mango's yield and quality. Fruit flies can cause fresh mango production loss ranging from 35% to 100% for late-maturing varieties (Ouédraogo, 2011; Simdé & Dakouo, 2017).

Some initiatives and plans have contributed to a comparatively smaller extent to the detrimental impacts of fruit flies in the nation by introducing fruit fly control technologies such as GF120 (Success-Appât). According to Tapsoba's (2018) and Bomi's (2022) adoption studies, the technology's high cost and lack of availability prevent it from being widely adopted. To address these drawbacks, research on developing a novel, more accessible, and efficient biopesticide based on yeast waste commenced in 2019. The goal of this research is to provide growers with a technology that can replace Success-Appât.

However, the scarcity of funds means that governments and backers are questioning the profitability of investments in research. Additionally, funding partners are increasingly questioning the effective use of funds allotted to agricultural research and extension as they must make trade-offs to meet the many demands they are facing. Therefore, it seems that national research and extension services should assess their programs in order to provide insight into the financial viability of the investments. The primary inquiry at this point in the biopesticide's development is: "What is the ex-ante economic impact of research into a new biopesticide for controlling mango fruit flies, in terms of improving the well-being of growers and consumers in Burkina Faso?".

The purpose of this study is primarily to offer insightful data that will assist the different stakeholders in determining if funding research is worthwhile. Secondarily, the purpose of this study is to assess the economic benefits of developing a new biopesticide to control fruit flies in advance (ex-ante) in order to improve the lives of Burkina Faso's growers and consumers.

2. Theoretical Foundations

2.1. Theoretical Framework

Griliches' (1958) economic surplus theory serves as the foundation for the evaluation of a new biopesticide made from yeast waste's possible economic impact on mango production. By contrasting a scenario without research with one that has research, the economic surplus approach to evaluating the economic impact of agricultural research can be applied. The adoption of an improved technology enables for production at a lower cost or more production at the same cost than with traditional technologies. This is the fundamental idea behind the economic surplus concept in agricultural research impact assessment.

Economic surplus draws attention to the relationship between the effectiveness of welfare programs and the factors that determine the amount and distribution of costs and benefits associated with research. It also highlights the assumptions that have been made about the following: the nature of the shift in demand and supply curves that research causes, supply and demand elasticities, the dynamics of the flow of benefits and costs, trade concerns and regional spillover effects, and uncertainty regarding potential gains in terms of increased production and quality, research success, and adoption level (Wangithi, 2019).

The economic surplus approach calculates the return on investment by adjusting for changes in consumer and producer surplus resulting from research-driven technological advancements. It calculates the return on investment by measuring the benefits of research in terms of the variation in consumer and producer excesses as a result of technological change, and it uses the estimated economic excess along with research expenses to calculate the Internal Rate of Return (IRR) or other benefits-cost metrics. The most frequently computed indicators are the Benefit-Cost Ratios (BCRs), the Internal Rate of Return (IRR), and the Net Present Values (NPVs) of agricultural research. Both economic and agricultural production data are needed for this framework. Economic and agricultural production data are needed for this framework.

According to Nikam et al. (2019), the economic surplus approach is founded on the idea of forecasting shifts in supply and demand as well as curves based on adjustments in yield and input costs brought about by the adoption of new technology. When a new technology is adopted, the supply curve is shifted to the right, increasing producer and consumer surpluses and lowering the unit cost of production. The new technology helps producers by lowering the cost per unit of production, while consumers benefit from being able to consume more at a reduced cost. The elasticities of supply and demand curves, as well as the size and type of the supply shift, determine how producers and consumers split profits. The vertical shift is assumed to be parallel to the supply function and the supply and demand curves to be linear in the model. The supply curve shifts as a result of the decrease in production costs per unit of product. This change could occur parallelly (Masters & Sanders, 1994) or pivotally at the beginning (Griliches, 1958; Akino & Hayami, 1975). The total of the changes in producer and consumer surplus is used to calculate the overall gain or benefit from this shift.

This study is based on the assumption of a parallel shift in the supply curve. It postulates that the adoption of innovation causes a parallel shift in the supply curve from a_0S_0 to $a_0''S_2$ (distance *J*) along the same demand line D_0 (**Figure 1**).

From **Figure 1**, distance *J* measures the increase in production due to the technology. The total net variation in economic surplus caused by a variation in supply is represented by the parallelogram a_0efa_0' (in light grey in **Figure 1**) and the triangle efg (in dark grey in **Figure 1**). The total potential (ex-ante) increases in social profits (for both producers and consumers combined) is represented by the sum of these areas. Thus, calculating economic surplus simply

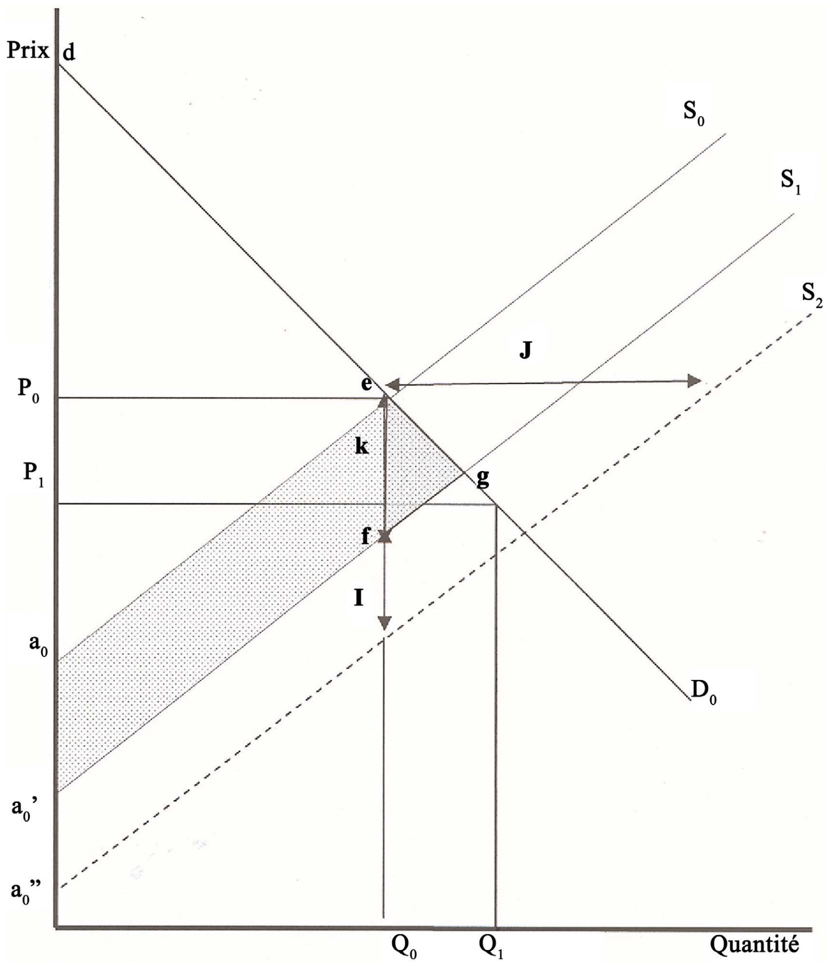

Figure 1. Economic surplus model. Source: Masters and Sanders (1994).

involves figuring out the parallelogram's and triangle's areas (Masters & Sanders, 1994). This area is then equal to efQ_0. The distance $ef = k$ represents the net gain in terms of production cost reduction induced by the new technology. This distance is measured by the relationship $k * P_0 = j/E_o - c$ (Masters & Sanders, 1994): where k is the change in net cost of production proportional to the price of the product; P_0, the real price to producers; j the proportional change in total production due to improved varieties; E_o, the elasticity of supply and c the proportional cost of adopting the new technology (yeast waste biopesticide). The area of the parallelogram is therefore equal to: $k * P_0 * Q_0$; with Q_0, the quantity produced of the product (fresh mango).

The area of the triangle is given by the following Formula (1):

$$\frac{1}{2} ef * \Delta Q = \frac{1}{2} k * P_0 * \Delta Q \quad (1)$$

where ΔQ is the difference between the quantities produced with the yeast waste biopesticide and the Success-Appât ($\Delta Q = Q - Q_0$).

$$\Delta Q = Q_0 * E_o * E_d * k/(E_o + E_d) \quad (2)$$

where E_d, being the elasticity of demand and E_o, the supply side.

As a result, the following Formula (3) yields the Gross Social Gain (GSG):

$$\text{GSG} = k * P_0 * Q_0 - \frac{1}{2} k * P_0 * \Delta Q \quad (3)$$

Net Social Gain (NSG) is calculated using the following Formula (4):

$$\text{NSG} = \text{GSG} - \text{RC} - \text{EC} \quad (4)$$

where RC is Research Costs and EC is Extension Costs.

2.2. Conceptualizing the Economic Surplus Method Used in the Study

The conceptualization of an estimation of the possible harm that fruit flies could have caused in the absence of any control measures is displayed in **Figure 2**. The counterfactual used to assess different approaches to reducing fruit fly damage is the "no control" scenario. If no control measures had been implemented, this scenario aims at quantifying the monetary losses incurred by fruit flies on mangoes. Based on the supply and demand curves for fresh mangoes, **Figure 2** presents its analysis. The supply curve for fresh mangoes (the quantities that mango producers would be willing to supply to the market under different scenarios) is represented by the straight line S_0, while D_0 represents the demand curve for mangoes (the quantities that mango consumers would be willing to buy under different market scenarios).

The value of additional consumer utility obtained by being able to purchase mangoes for less than they would be willing to pay is known as consumer surplus, or area $a_0 P_0 b$. The area $a_0 P_0 i_3$, on the other hand, represents the additional revenue above cost that producers obtain from selling mangoes at a price higher than what they would be willing to sell. This indicates the producer surplus.

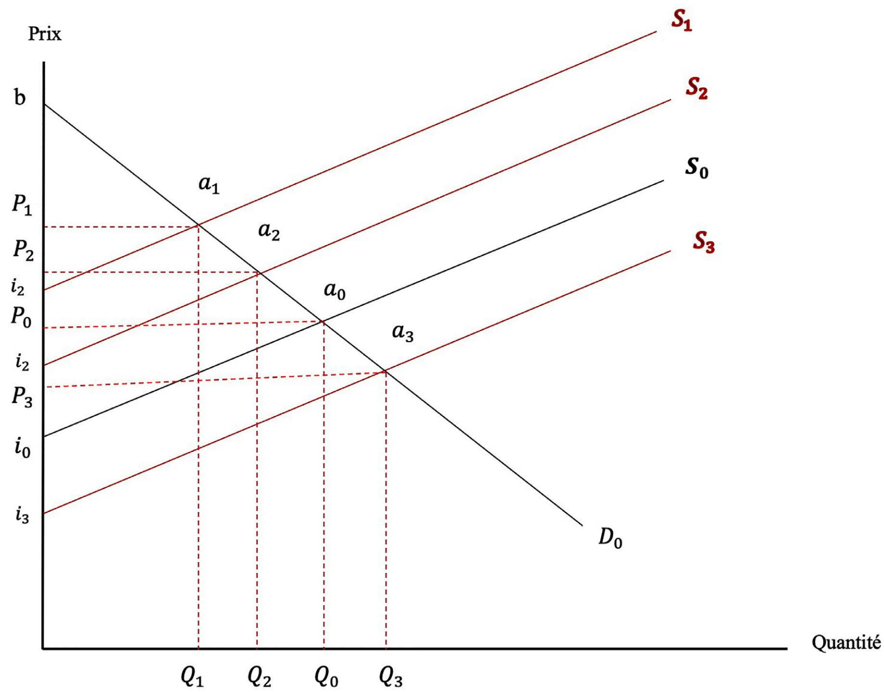

Figure 2. Economic surplus model conceptualized with the new biopesticide.

The scenario of "no fruit fly control in orchards" is taken into consideration in the first step. If there is no way to keep flies out of the orchards, the loss of yield from fruit flies' attacks will increase these marginal costs, which will cause the supply curve to shift upward and specifically to the left, from S_0 to S_1. This is because the supply curve represents marginal costs. Then, a_1P_1b is subtracted from the consumer surplus area. The reason for this change is that, although someone who initially paid P_0 can no longer afford it, mango consumers will now pay a higher price. Figure 2 illustrates that the difference between the area a_0P_0b and a_1P_1b is the measure of variation for the producer surplus in Scenario 1. Wangithi (2019) states that there may be a positive or negative net effect on producer welfare. Factors such as Q_1 to P_1 show that producers would have to sell fewer mangoes at a higher price due to the uncontrollably high environment of fruit flies' attacks. A fruit fly attack's net welfare loss can be represented by the area $a_0a_1P_0i_3$, which is the sum of variations in consumer surplus and mango producer surplus.

Two scenarios are used to model the benefits of fruit fly management in the second stage. In Scenario 2, mango farmers attempt to reduce fruit flies' damage in their orchards by using the GF120-based fruit fly control method in response to fruit flies' attacks. When comparing this scenario to Scenario 1 "without control," the new supply curve shifts to the right in S_2, indicating that GF120-based fruit fly management protects against yield loss in mango orchards. Nevertheless, the costs of protection incurred raise production costs above what they were prior to the arrival of mango fruit flies, so this method will fail to bring the market back to its initial equilibrium. When compared to the "no control" scenario, the decrease in economic losses serves as a proxy for the benefits of Success-Appât (GF120).

In Scenario 3, growers only begin treatment when the economic threshold of fruit flies' nuisance is crossed that is, when the equivalent value of the expected yield loss exceeds the cost of control after being exposed to the yeast waste biopesticide innovation. As long as this biopesticide takes the place of GF120 (Success-Appât), the new biopesticide based on yeast waste and GF120 control will coexist on the market. Furthermore, mango growers need time to fully adopt this innovation. Unlike GF120, which has been introduced and is not very accessible to burkinabè farmers, it aims to be an efficient and accessible replacement for them. Therefore, when comparing the supply curve of scenario S_2 with the use of GF120 for fruit flies control, the lower costs of controlling fruit flies with the yeast waste-based biopesticide will cause a shift to the right (S_3). Thus, area $a_3P_3i_3$ represents the producer's surplus, and the more marketable mangoes that growers can produce at a lower cost, the greater the benefit to them. Mangoes are more abundant in the market, which will allow consumers to purchase them for less money. Thus, from the area a_2P_2b to a_3P_3b, the consumer surplus will shift. In brief, the area $a_2a_3i_2i_3$ represents the economic surplus resulting from the changes in consumer and producer surplus from Scenario 2 to Scenario 3.

It is good to note that the demand curve is still inelastic because consumers expect to pay more for certain fruits and vegetables because they view them as luxury goods. Market stakeholders, however, think that customers are resolute when it comes to prices and will continue to purchase goods even if their prices increase. According to Carrico et al. (2022), mangos are a luxury good that consumers are always willing to pay more for.

3. Methodology

3.1. Study Area

The majority of the nation's mango production (more than 75%) is found in Western Burkina Faso. This region receives the most rainfall in the country. The decision is supported by the fact that these two regions are part of the project's area, which supports the Regional Plan for the Control of Fruit Flies in West Africa (PLMF). In these regions, biopesticides derived from yeast waste are being experimented for the control of fruit flies. Three provinces were chosen for this study: one (Comoé) in the Cascades region, two in the Hauts-Bassins region, and one in the Houet and Kénédougou region. In this study, other producing regions were left out because the primary varieties that are grown there are early-maturing ones, so they can partially escape fruit flies' damage. The Comoé province is situated at 9˚25 and 10˚37 north latitude and 3˚50 and 4˚46 west longitude. With nine departments and two hundred and nine villages, the province covers a total area of 15,597 km^2 (INSD, 2017). Kénédougou is a province of the Hauts-Bassins region. It is located between 10˚10' and 12˚05' north latitude and 4˚30' and 5˚30' west longitude. This province includes 170 villages spread across 13 departments and one urban commune (INSD, 2017). The Houet province is distant from Ouagadougou the capital Ouagadougou by 365 km. The city of Bobo-Dioulasso located in this province is the capital of the Hauts-Bassins region. The Houet province covers a total area of 12,715 km^2 area is home to 210 villages, 13 departments, 10 rural communes, 1 urban commune, and 1 department (INSD, 2017) (see **Figure 3**).

3.2. Sampling Procedure and Size

This study's sample came from mango growers. The study used a multi-stage sampling technique. In the first phase, two regions with a high concentration of mango production where fruit flies' attacks primarily affect late-maturing varieties were selected. Three provinces including Kénédougou, Comoé, and Houet were judiciously chosen for the second phase. Lastly, the sample size was estimated using general statistics based on the proportion's method. The following formula was used to determine the sample size:

$$N = \frac{t^2 * p(1-p)}{e^2};\ N = 341 \text{ mango farmers}$$

where N: number of people to be interviewed; $t = 1.96$ follows the student statistic e: the desired precision (here 5% error is tolerated, i.e. a 95% confidence interval). According to the Ministry of Agriculture (MARHASA, 2011), the proportion of mango growers is ($p = 0.33$ either 33%) in Burkina Faso. Thus, we deduce

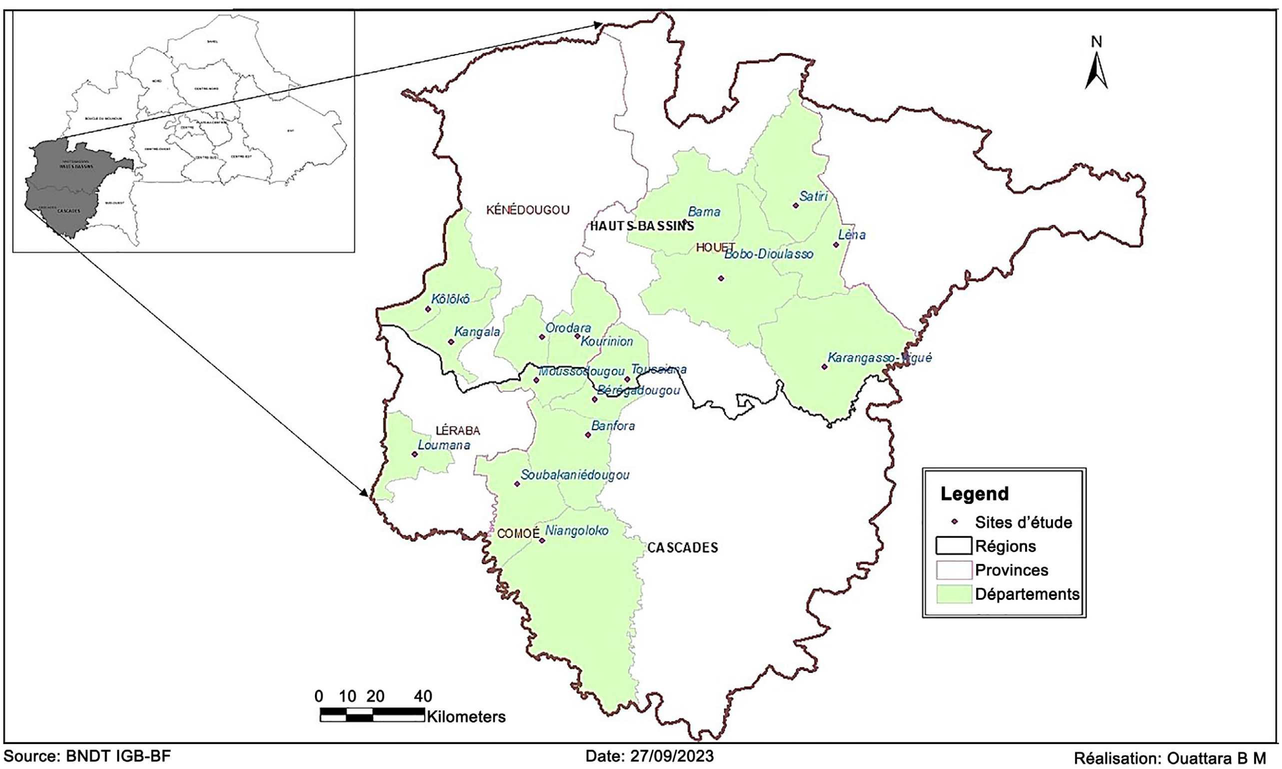

Figure 3. Survey site locations.

that the sample size n is equal to 341 mango growers. Furthermore, the selection of these growers was done randomly and based on the list of growers drawn up by the mango interprofession (APROMAB, 2022). The mango growers involved in this survey were essentially those with at least 0.25 ha of mango orchards.

3.3. Data Collection and Analysis

Both primary and secondary data, both were gathered. National statistics, journals, and articles provided secondary data on elasticity, prices, technology and extension costs, and discount rates. Secondary data were gathered from administrative organizations and resource people. Primary data were gathered using a questionnaire administrated to mango farmers. This questionnaire focused on the potential adoption or non-adoption of the new biopesticide for fruit flies control among mango growers. In 2023, data were collected from February through April. DREAMpy (Dynamic Research Evaluation for Management) version 2.2 software was used for data analysis.

3.4. Empirical Framework

Because mango is Burkina Faso's main export fruit, we hypothesized that our economic model is a small open economy. This is even more reasonable considering that the companies engaged in the production of organic mangoes are focused on exports in order to maximize profits and maintain competition. Although a portion of the production is exported, the equilibrium price in this open market is solely set by external supply and demand. The demand and supply curves were also assumed to be linear, with the use of research findings for the new biopesticide causing a shift in the supply curve to the right. Based on the work of Alston et al. (1995) and Wangithi (2019), the annual change in consumer surplus (ΔSC), producer surplus (ΔSP) and total economic surplus (ΔSE) from biopesticide research can be calculated as follows (Equations (5)-(7)):

$$\Delta SC_t = P_0 Q_0 z\left(1 + 0.5 Z_\eta\right) \tag{5}$$

$$\Delta SP_t = P_0 Q_0 \left(k - z\right)\left(1 + 0.5 Z_\eta\right) \tag{6}$$

$$\Delta SE_t = P_0 Q_0 k\left(1 + 0.5 Z_\eta\right) \tag{7}$$

where: P_0 and Q_0, are the initial equilibrium price and quantity; k is the vertical proportion of the shift in the supply curve linked to the potential adoption of the biopesticide, expressed in terms of costs per unit of production; z is the price decrease resulting from the shift in the supply curve; η is the absolute value of the price elasticity of demand and ε is the price elasticity of supply.

The vertical shift of the supply function at time t (K_t) and the relative fall in prices (Z_t) are calculated as follows (Equation (8)):

$$K_t = \left\{\frac{\Delta Y}{\varepsilon} - \frac{\Delta C}{1 + \Delta Y}\right\} \times A_t \tag{8}$$

where: ΔY is the expected proportional variation in yield due to the adoption of the yeast waste-based biopesticide; ΔC is the expected proportional change in variable input costs to induce the expected yield increase.

A_t is the adoption rate. In other words, it is the proportional area of mango trees under the yeast waste biopesticide in relation to the total area of mango orchards. For the purposes of this study, we will rely on the analysis of the results from primary data collected from mango growers. Indeed, the logistic function/curve of Alston et al. (1995) and the set of farmers' responses on their willingness to adopt the yeast waste-based biopesticide at time t were used to describe the trajectory of biopesticide adoption for the protection of mango production. Indeed, adoption of the technology starts slowly, followed by a period of rapid growth as it is scaled up, and then reaches its maximum. The level of adoption in a given year is estimated as follows (Equation (9)):

$$A_t = \frac{M}{1+\mathrm{e}^{(-a+bt)}} \tag{9}$$

This formula is transformed into an equation with the logarithmic function and parameters estimated with the Ordinary Least Squares (OLSs) method (Wangithi, 2019). This Equation (10) takes the following form:

$$\ln\frac{A_t}{M-A_t} = a + bt + \varepsilon \tag{10}$$

where M, is the maximum adoption rate; b is an adoption parameter; a is the constant; t is time in years; e is the base of the natural logarithm; ε is the error term.

In addition, we mention other key parameters needed to estimate economic surplus:

- ✓ The research period, defined as the time between the start of the research and the design of the biopesticide ready for extension. In the specific case of this research, this is five years;
- ✓ Research Costs (RC) are the resources required to develop the yeast waste-based biopesticide innovation, including the salaries of the researchers and technicians involved. Data on research costs were collected from INERA's accounting department. These include the funds allocated by CEAS to support the research team, coupled with the salaries of team members during the research period;
- ✓ Extension costs (CV) are the costs of extension services provided by the Ministry of Agriculture for similar products (salaries of extension officers, fuel and subsidies). In the context of this research, these costs are nil, as the extension services are not directly involved in the technology's extension system, as is commonly done for improved varieties, where demonstration plots are set up by the government's extension services;
- ✓ Market Data: This includes data on mango production quantities, mango prices, price elasticities of supply and demand, and the discount rate. Elasticity is the proportional change in quantity induced by a change in price. Consequently, supply elasticity is defined as the proportional variation in quanti-

ty offered induced by a variation in price. Demand elasticity is defined as the proportional change in quantity purchased induced by a change in price;

- ✓ Data on biopesticide adoption, i.e. the percentage of mango farmers likely to adopt the yeast waste biopesticide after extension. The likelihood of the biopesticide being used by farmers, and the time it will take for them to adopt it to the maximum level, are essential to explain the shift in the supply curve induced by the research. Indeed, the adoption of the registered biopesticide is then often assumed to start immediately at the end of the research project period, then follow a sigmoid curve whereby adoption starts very slowly, gradually accelerates, then decelerates until the adoption ceiling is reached. The two parameters that define the adoption period are: 1) the time to maximum adoption (the adoption lag) and 2) the adoption ceiling or maximum adoption level (Thornton, 2006). An estimate of the adoption ceiling is based on two key elements: 1) the scope of the problem addressed by the research and 2) the proportion of end-users (farmers) who are likely to adopt the final biopesticide based on the research. As for the maximum adoption rate, it represents the period when the vast majority of farmers will have been exposed to the biopesticide and will have made the decision whether or not to adopt it. The highest level of adoption is probably reached after the biopesticide has been scaled up. The Potential Adoption Rate (PAR) is the ratio between the number of individuals adopting a product (generally an innovation) and the total potential user population (Equation (11)). It is expressed as a percentage, as follows:

$$\text{PAR} = (\text{NA}/\text{NT}) * 100 \tag{11}$$

where PAR: Potential Adoption Rate, NA: Number of farmers wishing to adopt the yeast waste biopesticide and NT: Number of potential user farmers (all mango growers surveyed).

The main indicators for measuring economic profitability include:

- The Net Present Value (NPV) is estimated using the economic surplus and research expenditure to calculate profits. It is calculated as follows (Equation (12)):

$$\text{NPV} = \frac{R_t}{(1+i)^t} \tag{12}$$

where: t representing the time of cash flows and R_t, representing net cash flow, i.e. cash inflows minus cash outflows at time t.

- The IRR is defined as the discount rate at which the NPV is exactly zero. It is calculated using the following Formula (13):

$$\text{IRR} = \alpha + \left[\frac{VAN_a}{VAN_a - VAN_b} \times (b-a)\right] \tag{13}$$

where: a is the lowest discount rate; VAN_a, is the NPV at the lowest discount rate; b is the highest discount rate and VAN_b, is the NPV at the highest discount rate.

4. Results and Interpretations

4.1. Parameters of the Economic Surplus Model

The different parameters that the economic surplus model used to determine the primary indicators are displayed in **Table 1**. Secondary data were gathered from administrative organizations and resource people. Indeed, the supply and demand elasticities are derived from local empirical research. Nothing is known about the Burkina Faso-specific elasticities. We have thus considered those that are frequently applied to the Sub-Saharan African region. Supply and demand are respectively 0.8 and 0.4 (Allarangaye et al., 2001). Stated differently, for every 1% increase in price, the supply rises by 0.8% while the quantity demanded decreases by 0.4%. **Table 3** also reveals that, according to data from the mango interprofession (APROMAB, 2019), 246,660 tons of organic mangoes were produced in 2019 and 100,000 tons were exported. According to the same source, the international price of fresh organic mangoes charged by national exporters is 600,000 FCFA per ton. In light of the results presented in **Table 1**, the biopesticide's yield gain over the reference control (Success-Appât) is 12%. Based on Tassembédo et al. (2023), the biopesticide's innovation cost reduction is 78.21% when compared to the registered control product (Success-Appât). In terms of the biopesticide's probability of success, we used the best estimates of the researcher regarding the timeframe and probability of research success. The developer estimated the biopesticide's probability of success at 75% given the threat that fruit flies pose to Burkina Faso's mango production. For the discount rate, we will use the interest rate applied by the Agricultural Bank of Burkina Faso (BABF), which is 3.5%.

Table 1. Parameters used in the economic surplus model.

Parameters	Value	Sources
Supply elasticity	0.8	Allarangaye et al. (2001)
Demand elasticity	0.4	Allarangaye et al. (2001)
Mango production in 2019 (in tons)	246,660	APROMAB (2019)
Mango exports in 2019 (in tons)	100,000	APROMAB (2019)
Selling price per ton of fresh organic mangoes for export (FCFA)	600,000 (992 US$)	APROMAB (2019)
Yield gain over reference control	12%	Tassembédo et al. (2023); Author
Technology cost reduction	78.20%	Tassembédo et al. (2023), Author's calculation
Probability of success in R&D	75%	Searcher
Discount rate	3.50%	Agricultural Bank of Burkina Faso (BABF)

4.2. Potential Adoption Rate

Table 2 shows the adoption rates of biopesticides at the end of the research period,

Table 2. Potential biopesticide adoption rate among mango growers.

Adoption rate	Percent	Source
Minimun adoption rate	36.8%	Bomi (2022)
Maximum potential adoption rate	92.08%	Survey data 2023; Author

Source: Author (2023).

when most producers will have had enough exposure to the product to make an informed decision about whether or not to adopt it. Here, the highest rate of adoption is dictated by the desire of producers to apply the yeast waste-derived biopesticide as soon as it becomes accessible. Out of a sample of 341 producers surveyed, 314 growers said that they would be willing to employ the biopesticide, indicating a possible adoption rate of 92.08%. The biopesticide can be employed instead of Success-Appât, therefore the minimal adoption rate will be ascertained using the Bomi's (2022) data. Success-Bait was adopted by mango growers there at a 36.8% rate.

4.3. Research Cost

The entire biopesticide development process was considered when estimating research costs. Component identification, fruit fly rearing, formulation testing in the lab, multi-location trials in farmers' fields, and registration are all steps in the development process. Thus, input costs (yeast waste, mango, product preparation equipment, *Jatropha curcas*' seeds, etc.) and breeding expenses are included in the costs of research, as are the salaries of researchers and technicians. Costs for analysis, pre-extension, and certification are also considered. **Table 3** lists the yearly expenses related to the development of the biopesticide.

Table 3. Biopesticide research costs.

Year	Research cost (FCFA)	Converted in dollar (100 US$)
2019	7,100,000	117.36
2020	12,100,000	200.00
2021	17,150,000	283.47
2022	23,150,000	382.64
2023	3,000,000	49.59

Source: Author (2023); 1 US$ = 605 FCFA.

4.4. Economic Impact Results and Interpretations

The simulated equilibrium variations in supply and demand for produced and consumed mangoes are displayed in **Table 4**. It gives each group of economic agents (Producers and Consumers) two scenarios: one with no research (Scenarios 1 and 2), and another with research (Scenario 3). We assumed a small, open economy for the purposes of this study, with some production being exported.

Table 4. Projected social gains ('00 USD), changes in quantities produced and consumed ('000 Tonnes) and prices (USD) due to biopesticide (research).

Year	Production					Consumption				
	No research (no biopesticides)		With research (with biopesticide)			No research (no biopesticides)		With research (with biopesticide)		
	Price	Quantity	Price	Quantity	Benefits	Price	Quantity	Price	Quantity	Benefits
	US$/T	1000 T	US$/T	1000 T	100 US$	US$/T	1000 T	US$/T	1000 T	100 US$
2019	992.00	246.66	992.00	246.66	0.00	992.00	100.00	992.00	100.00	0.00
2020	992.00	246.66	992.00	246.66	0.00	992.00	100.00	992.00	100.00	0.00
2021	992.00	246.66	992.00	246.66	0.00	992.00	100.00	992.00	100.00	0.00
2022	992.00	246.66	992.00	246.66	0.00	992.00	100.00	992.00	100.00	0.00
2023	992.00	246.66	992.00	246.66	0.00	992.00	100.00	992.00	100.00	0.00
2024	992.00	246.66	992.00	262.58	20371.27	992.00	100.00	992.00	100.00	0.00
2025	992.00	246.66	992.00	278.49	42015.85	992.00	100.00	992.00	100.00	0.00
2026	992.00	246.66	992.00	294.41	64933.75	992.00	100.00	992.00	100.00	0.00
2027	992.00	246.66	992.00	310.32	89124.97	992.00	100.00	992.00	100.00	0.00
2028	992.00	246.66	992.00	326.24	114589.51	992.00	100.00	992.00	100.00	0.00
2029	992.00	246.66	992.00	342.15	141327.36	992.00	100.00	992.00	100.00	0.00
2030	992.00	246.66	992.00	358.07	169338.53	992.00	100.00	992.00	100.00	0.00
2031	992.00	246.66	992.00	358.07	169338.53	992.00	100.00	992.00	100.00	0.00
2032	992.00	246.66	992.00	358.07	169338.53	992.00	100.00	992.00	100.00	0.00
2033	992.00	246.66	992.00	358.07	169338.53	992.00	100.00	992.00	100.00	0.00

Source: Author (2023), 1 US$ = 605 FCFA.

The base year's secondary data are used in this study, and the five years that were spent on the biopesticide's development and registration are represented by the research costs. Based on a review of Table 4, it can be concluded that the production of fresh mangoes starts to rise the year the biopesticide technology is increased to the benefit of mango growers. The supply of mangos is steadily increasing concurrently, reaching a peak in 2030. However, during the research phase, research-induced profits are zero, and they begin to turn a profit only in the first year of the biopesticide technology scaling-up. Over the last four years, sales prices have not changed. However, as more biopesticide is produced, the advantages of using it in production grow. This indicates that by applying the research's findings (biopesticide made from yeast waste), mango growers are optimizing their financial gains.

Results in Table 4 indicate that during the simulation period, both purchase prices and consumption quantities of organic mangoes stayed constant. Thus, even as production volumes rise, consumers do not gain any profit. The open market and diverse consumer base help to explain this result. Furthermore, under this kind of market, consumer profits are zero because it is assumed that quantities demanded and purchase prices will not change during the simulation period. For the players in the mango sector, this kind of market is, in short, more profitable.

The ex-ante analysis of the economic effects of biopesticide research and extension on mango production is shown in **Table 5**. A 15-year timeframe is used to simulate this impact, with 2019 serving as the base year and a 3.5% discount rate. Since research must go on and it will take at least five years to come up with another, more effective innovation, it was assumed for the purposes of this study that it would take seven years to find an alternative to this biopesticide. Furthermore, because the study is primarily focused on the consumption of organic mangoes (using organic fruit fly management technologies), it is more focused on the global market.

Table 5 also demonstrates that in this small open economy, the only people who benefit from this situation are the mango growers, who are estimated to have a surplus of 76,836,954 US$ either 46,486,357,170 FCFA, compared to 0 US$ either 0 FCFA for consumers. Because of the introduction of the biopesticide,

Table 5. Producer surplus, consumer surplus, economic surplus, research costs, net present value, internal rate of return.

Years	Producer surplus	Consumer surplus	Economic surplus	Costs	Net Present Value (NPV)
Unity	100 US$	100 US$	100 US$	100 US$	100 US$
2019	0.00	0.00	0.00	117.36	−117.36
2020	0.00	0.00	0.00	200.00	−200.00
2021	0.00	0.00	0.00	283.47	−283.47
2022	0.00	0.00	0.00	382.64	−382.64
2023	0.00	0.00	0.00	49.49	−49.49
2024	20371.27	0.00	20371.27	0.00	20371.27
2025	42015.85	0.00	42015.85	0.00	42015.85
2026	64933.75	0.00	64933.75	0.00	64933.75
2027	89124.97	0.00	89124.97	0.00	89124.97
2028	114589.51	0.00	114589.51	0.00	114589.51
2029	141327.36	0.00	141327.36	0.00	141327.36
2030	169338.53	0.00	169338.53	0.00	169338.53
2031	169338.53	0.00	169338.53	0.00	169338.53
2032	169338.53	0.00	169338.53	0.00	169338.53
2033	169338.53	0.00	169338.53	0.00	169338.53
			SUMMARY OF INDICATOR VALUES		
	Producer surplus	Consumer surplus	Economic surplus	NPV	TRI (%)
	76,836,954 US$	0.00	76,836,954 US$	76,740,608 US$	190.54
1 US$ = 605 FCFA	46,486,357,170 FCFA	0.00	46,486,357,170 FCFA	46,428,067,840 FCFA	

Source: Author (2023).

which is far less expensive than the marketed food bait (Success-Appât), they actually make more money because the prices charged are higher than the cost of production. However, since the quantity and purchase price of mangoes have not changed, customers are not profiting. Reducing health risks from chemical pesticide residues is one of the effects of using this biopesticide instead of the costly Success-Appât on consumers.

Profit Gain: The results of the above table show that investment in biopesticide research would generate social benefits amounting to 76,836,954 US$ either 46,486,357,170 FCFA. This is a very interesting result, given that mango cultivation is only practiced in a few provinces of the country.

Net Present Value (NPV): This study's simulation results yield a very appealing net present value of 76,740,608 US$ either 46,428,067,840 FCFA. This finding suggests that investing in biopesticides is both financially feasible and profitable. Put differently, this finding points to the necessity of funding additional studies to develop a biopesticide for the management of mango fruit flies.

Internal Return Rate (IRR): Based on this investigation, an estimated 190.54% was the internal rate of return. Thus, 100 FCFA spent on the development and application of biopesticides would result in 190.54 FCFA. Compared to alternative investments, this investment project would yield higher profits. By having a very high solvency capacity, the biopesticide is thus viable. This is more than twice as high as the IRR (82.3%) that Ouédraogo (2004) found in his investigation in the financial effects of improved maize variety research and extension in Burkina Faso. This indicates that compared to plant breeding, much more money is spent on fruit flies control technology research.

4.5. Sensitivity Analysis

The economic surplus, NPV, and IRR will all be simulated in our instance. These include the discount rate, the return and expenses of research, the price elasticities of supply and demand, and the likelihood that the biopesticide technology will succeed.

Effect of Probability of Success: Assuming a 25% chance of research success, the NPV drops by 70.21% and the economic surplus significantly decreases by 70% (**Table 6**). For NPV, the same holds true. IRR decreased by 29.18%. This indicates that if there is little chance that the biopesticide technology will succeed, the various interesting indicators will be less interesting. In another way, the likelihood that growers will find success with biopesticide research influences the amount of profit that can be made from it. By analogy, we can state that social gain, net present value, and IRR would all rise in the event that the biopesticide's success rate was high.

Effect of Discount Rate: A closer look at **Table 7** reveals that the NPV and the Social Gain (SG) are inversely correlated with the discount rate. There is a significant decrease in social gain of 85%, NPV of 85.14%, and IRR of 29.45% when the discount rate is raised to 10%. This indicates that the IRR is high enough and that the discount rate cannot exceed it under any normal economic scenario. Put another way, it would be extremely difficult, if not impossible, for interest rates to reach 190% in a typical economic environment. In contrast, a decrease in the discount rate relative to the benchmark would lead to an increase in the SG and NPV.

Effect of Variations in Yield and Production Costs: Assuming that the yield level of the Success-Bait is equal to a 50% increase in production costs (inflation) plus a 12% decrease in yield (reduction in the biopesticide's effectiveness against fruit flies), all three profitability indicators suffer: The Social Gain decreases by 78.21% to 16,741,761 US$, NPV drops to 16,645,414 US$, and the IRR increases to 122.24%, resulting in a 35.85% reduction (Table 8). Should the technology cost double from the starting point, the SG and NPV will decrease by nearly the same amount (5.08% and 5.09%, respectively). With respect to the first scenario, the IRR would be 187.92%, a decrease of 1.38% (Table 8). By analogy, a rise in yield and a fall in research expenses inevitably cause an increase in each of the three indicators.

Effect of Price Elasticities: Results presented in Table 9 demonstrate that price elasticities rather than net social gain have a higher impact on how benefits are distributed between producers and consumers. A natural disaster or an increase in the price of raw materials can cause a 37.5% reduction in supply elasticity, which increases producer surplus while decreasing consumer surplus. This means that a significant decline in consumer purchasing power would result from

Table 6. Sensitivity analysis of the probability of research success.

Parameters	Economic surplus	Δ%	NPV	Δ%	IRR (%)	Δ%
Initial scenario	76,836,954		76,740,608		190.54	
			(Reference = 75%)			
25%	**22,949,812**	**−0.70**	**22,853,464**	**−70.22**	**134.94**	**−29.18**

Table 7. Discount rate sensitivity analysis.

Parameters	Economic surplus	Δ%	NPV	Δ%	IRR (%)	Δ%
Initial scenario	76,836,954		76,740,608		190.54	
			(Reference = 3.5%)			
10%	**11,489,188**	**−85.05**	**11,403,714**	**−85.14**	**134.42**	**−29.45**

Table 8. Sensitivity analysis of yield variation and cost variation.

Parameters	Economic surplus	Δ%	NPV	Δ%	IRR (%)	Δ%
Initial scenario	76,836,954		76,740,608		190.54	
			(Reference = 78.2% for production cost and 12% for yield)			
(Yield = −12%; Cost = 50%)	**16,741,761**	**−78.21**	**16,645,414**	**−78.31**	**122.24**	**−35.85**
Cost = 50%	**72,929,317**	**−5.08**	**72,832,970**	**−5.09**	**187.92**	**−1.38**

Table 9. Sensitivity analysis of supply and demand price elasticities.

Parameters	Economic surplus	Δ%	NPV	Δ%	IRR (%)	Δ%
Initial scenario	76,836,954		76,740,608		190.54	
	(Reference = 0.8 for supply; 0.4 for demand)					
−37.5% for supply	69,348,655	−9.75	69,252,308	−10.81	188.38	−0.5
75% for demand	76,836,954	0.00	76,740,608	0.00	190.54	0.00

this drop-in supply elasticity. Thus, social gain is adversely affected (9.75%). This also holds true for NPV (10.81%). There would be a notable decrease in the IRR (0.5%). Regarding demand elasticity, three indicators (GS, NPV, and IRR) show no change when the availability of biopesticide substitutes is increased by 75% as compared to the initial scenario. The open market provides an explanation for this.

5. Conclusion

The goal of the research is to develop agricultural technologies that are biologically accessible to users and increase productivity without harming the environment to achieve sustainable food and nutrition security. In fact, the economic surplus model simulation results over 15 years show that biopesticide research investments are economically more profitable than alternative investments. Secondly, the estimated NPV is 76,740,608 US$ (46,428,067,840 FCFA) and the estimated social gain is US$76,836,954 (46,486,357,170 FCFA). The estimated Internal Return Rate (IRR) for this research investment is 190.54%, which is higher than the interest rates that banks charge.

Supporting mango fruit fly research is necessary to consolidate the findings and address the problem of fruit flies in Burkina Faso, which has policy implications. A coordinated effort involving research, extension, and the private sector will also be necessary to pursue the development and scaling-up of the new biopesticide for the benefit of economic agents, given the higher yields and lower production costs for mangos.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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