Research Article

Received: 17 November 2022 Revised: 21 March 2023 Accepted article published: 11 May 2023 Published online in Wiley Online Library: 31 May 2023

(wileyonlinelibrary.com) DOI 10.1002/ps.7552

Economic and financial model to the mass-rearing of *Macrolophus pygmaeus* (Rambur) (Heteroptera: Miridae), a biological control agent against the tomato moth *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) in protected culture

Tiago Mota Dutra,[a,b] Maria da Graça Batista,[a,c] João CA Teixeira,[a,c] Silvia Todorova,[d] Luísa Oliveira,[e] João Tavares,[e] Isabel Borges[f] and António Onofre Soares[f*]

Abstract

BACKGROUND: *Tuta absoluta* (Meyrick) is a major pest of tomato produced in glasshouses and open field, causing severe damages to crops, reducing the quality of tomato fruits. The current maintenance of the pest populations below the economic threshold is not achieved by natural and classical control, thus requiring the continuous application of biological control agents (BCAs), under an augmentative or inoculative approach. The present study aims to develop an economic and financial model to evaluate the commercial viability of a continuous mass production of *Macrolophus pygmaeus* (Rambur), a BCA commonly used against the tomato moth, *Tuta absoluta*, in protected culture. The estimations for our model were based on two approaches: the farm-level impact analysis and the benefit–cost analysis.

RESULTS: The results of the farm-level analysis show that the adoption of a more sustainable biological control approach is profitable for farmers and the benefit–cost analysis provides evidence that the investment on a new factory dedicated to the mass rearing of *M. pygmaeus* to control tomato moth populations generates a positive net present value (NPV) of 7.2 million euros, corresponding to an internal rate of return (IRR) of 28.4% per year.

CONCLUSION: Our results are in line with (i) the more recent European Commission proposals for a new Regulation on sustainable use of plant protection products, which includes the reduction of 50% the use and risk of chemical pesticides by 2030 and (ii) most of the existing literature which conclude that new projects on BCA production are worth investments.

Keywords: *Macrolophus pygmaeus*; biological control; economic feasibility analysis; farm-level impact analysis; benefit–cost analysis

* *Correspondence to: AO Soares, cE3c – ABG – Centre for Ecology, Evolution and Environmental Changes and Azorean Biodiversity Group and CHANGE – Global Change and Sustainability Institute, Faculty of Science and Technology, Rua da Mãe de Deus, 9500-321 Ponta Delgada, S. Miguel, Açores, Portugal, E-mail: antonio.oc.soares@uac.pt*

a *School of Business and Economics, University of the Azores, Ponta Delgada, Portugal*

b *Business Research Unit (BRU-IUL), Lisbon, Portugal*

c *Centre of Applied Economics Studies of the Atlantic (CEEAplA), Ponta Delgada, Portugal*

d *Anatis Bioprotection Inc, Saint-Jacques-le-Mineur, Quebec, Canada*

e *CBA – Biotechnology Centre of Azores, Faculty of Sciences and Technology, University of the Azores, Ponta Delgada, Portugal*

f *cE3c – ABG – Centre for Ecology, Evolution and Environmental Changes and Azorean Biodiversity Group and CHANGE – Global Change and Sustainability Institute, Faculty of Science and Technology, Ponta Delgada, Portugal*

1 INTRODUCTION

In June of 2022, the European Commission (EC) has adopted proposals for a new Regulation on the sustainable use of plant protection products, which includes the European Union (EU) wide targets to reduce by 50% the use and risk of chemical pesticides by 2030, in line with the EU's Farm to Fork and Biodiversity strategies.[1] This new proposal revisits the existing rules of the former Directive 2009/128/EC on the sustainable use of pesticides.[2] One of the main measures of the new proposal is the environmentally friendly pest control seeking to ensure that all farmers and other professional pesticide users practice integrated pest management (IPM). This environmentally friendly system of pest control should include actions toward pest prevention and selection of alternative pest control methods, with chemical pesticides only used as a last resort.[2]

IPM and biological control of pest populations in agricultural systems are fundamental tools for sustainable food production since it provides a safe alternative to chemical control. Classical biological control, which is based on the importation of exotic natural enemies to control herbivorous pest populations, has led to over 6,000 deliberate introductions of more than 2,000 insects, to be applied as biological control agents (BCAs).[3] This approach, commonly used in the past, poses, however, important concerns for conservation biology.[4–6] One possible solution toward the maintenance of alien pest populations under the economic threshold, or even its full eradication, is the use of native natural enemies through the continuous applications of a high number of mass-reared insects, under augmentative or inoculative strategies. Mass- and laboratory-rearing of insects is a key component of IPM and requires the maximization of production, but regarding sustained quality and efficiency of released BCAs.[7,8] Despite commercial mass production of BCAs spanning a period of over 100 years,[9] mass rearing for market purposes is always challenging. Not only a general knowledge of the biology and ecology of insects, under different biotic and abiotic conditions, are needed, but information on the breeding efficacity and economic value is crucial. These components are essential to gain maximum yield and quality in insect production.[7]

The South American leaf miner *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) is an alien species and a major pest of tomato crops in Europe, causing damages ranging from 80 to 100%, in areas without control measures both in glasshouses and open field crops reducing the yield and quality of tomato fruits.[10–13] In addition, it has major impacts on other crops such as potatoes and eggplants.[11,14,15] The effect of this pest includes reduced production; limitation in the export of fresh tomatoes and planting and the intensification of the use of insecticides, associated with harmful consequences for producers, consumers, and the environment, as side effects of non-target organisms, pest resistance and disruption of natural biological control.[16–20] The use of BCAs is increasingly becoming a safe alternative.[18,21] According to a report from Global Market Insights,[22] the biocontrol agents market size exceeded three billion USD in 2018 and will increase by around 15% compound annual growth rate from 2019 to 2025, due to the replacement of synthetic chemicals in farming. For these reasons, the use of entomophagous insects, predators, and parasitoids, is an alternative technique for the IPM of *Tuta absoluta* in Europe.[16,18,23]

Macrolophus pygmaeus (Rambur) (Heteroptera: Miridae) is a zoophytophagous predator, native to the Palearctic region and it has been successfully used in the regulation of *Tuta absoluta* and other small arthropod pests, as whiteflies, particularly *Bemisia tabaci* (Gennadius) and *Trialeurodes vaporariorum* (Westwood) (Hemiptera: Aleyrodidae), thrips, spider mites and aphids.[24–35] Due to its success as a BCA, *M. pygmaeus* is among the most widely used invertebrate commercially available.[21]

Considering all the evidence on the benefits of using biological agents against *Tuta absoluta*, we propose to analyse the commercial viability of a continuous mass production of *M. pygmaeus* (Rambur). Several studies, such as Cullen *et al*., Waterfield and Zilberman, and Naranjo *et al*., have discussed the economic value of biological control techniques and possible methods to estimate it.[36–38] According to Naranjo *et al*.,[39] there are three main approaches studying the economic impacts of biological control. The first one is the farm-level approach, which focuses on investigating whether adopting biological control practices is profitable or not for farmers. In this approach, the partial budgeting method is commonly used, comparing farm revenues and costs if biological control is implemented. Partial budgeting is a framework for planning and decision-making, which is commonly used to compare the benefits and costs that a farm business faces when considering different alternatives. The focus of this approach is on the extra revenues and costs that will result when implementing a new or different alternative. This means that all the other items that are unchanged by the decision should be ignored. The partial budgeting approach provides information on how a decision will impact the profitability of the farm business. The second approach is based on market-level studies, where the goal is to understand how the adoption of biological control practices would impact an entire region, market, or economy. In this approach, the economic surplus method, i.e., an analysis of the demand *versus* supply curve, their shifts, and the definition of the equilibrium price and quantity, is used. Finally, the third and last approach consists of benefit–cost analysis. A benefit–cost analysis is a process where the projected or estimated costs and benefits associated with a specific project are compared, in order to determine (and help to decide) whether the project makes sense from an investing perspective. For this approach, a net present value (NPV) must be calculated to determine the economic feasibility of mass production of biological agents to control tomato moth. The NPV is the difference between the present value of cash inflows and the present value of cash outflows over a period of time. An NPV above zero means that the project is worthy of investment. To perform these calculations, a discounted cash flow (DCF) model is applied, where estimated revenues and operating costs of a certain project (public or private) are discounted to time zero at the proper risk rate, allowing to conclude of the projects' economic and financial viability.

The aim of this study is to develop an economic and financial model that allows the evaluation of the commercial viability of mass production of *M. pygmaeus* against the tomato moth, *Tuta absoluta* in protected culture.

2 MATERIAL AND METHODS

Three main approaches are commonly used by the literature[39] to study the economic impacts of biological control: (1) a farm-level approach; (2) market-level studies; (3) a benefit–cost analysis (DCF model).

Considering the existing literature[40–47] performing the market-level approach with most results indicating a net benefit of both producers and consumers when biological control practices are adopted, in this article the following only two approaches are performed to evaluate the commercial viability of mass production of BCAs against tomato moth, *Tuta absoluta*, in protected culture: (1) the farm-level impact analysis; and (2) the benefit–cost analysis.

2.1 Farm-level impact analysis

Farm-level impact analysis intends to determine to what extent the use of BCAs can be profitable for farmers. For this purpose, we looked for a set of the following information: What is the farmer selling price of 1 kg of tomato produced under different conditions (biological *versus* intensive production modes)? What are the costs required for farmers to acquire BCAs to produce a kilogram of tomato, in relation to the cost paid by farmers using chemical control? Answering these questions makes it possible to determine whether farmers will benefit economically by changing from chemical control to biological control practices and by way to predict whether farmers would be willing to adopt biological control methods against *Tuta absoluta*. Therefore, to conclude that the adoption of biological control is profitable for farmers, the condition represented in Eqn (1) must be verified.

$$SP_{BC}-SP_{CC}>BC_u-CC_u \quad (1)$$

where SP_{BC} represents the selling price of 1 kg of tomato produced using BCAs, SP_{CC} is the selling price of 1 kg of tomato under chemical control, BC_u represents the cost of BCAs enough for 1 kg of tomato, while CC_u stands for the cost of chemical control agents also enough for 1 kg of tomato.

2.2 Benefit–cost analysis (investor/factory perspective)

An analysis of the benefit–cost of a new project/investment becomes even more interesting after concluding that: (1) biological control practices are profitable for farmers, and (2) governments are committed to shift agricultural production from conventional to biological. A benefit–cost analysis is typically applied to evaluate biological control projects[48] or the benefit of a specific treatment.[49] In the current chapter, a DCF model is used to determine the NPV of an investment in a new factory dedicated to the mass-rearing of biological agents to control tomato moth.

This approach follows Copeland *et al.*[50] valuation method and foresees a three-step procedure: (i) define the concept, purpose, and time-horizon of the project; (ii) enumerate and estimate the inputs/costs and outputs/revenues of the project; and (iii) discount the estimated future cash flows (CFs) to time zero and determine the NPV of the project (current value of a future stream of payments).

The NPV is defined as follows:

$$NPV=-I_0+\sum_{t=1}^{\infty}\frac{(R_t-C_t)}{(1+r)^t} \quad (2)$$

where I_0 stands for the projects' initial investment, and R_t and C_t are the estimated revenues and operating costs at time t, respectively. The risk rate to discount the CFs to time 0 is given by r.

Theoretically, a positive NPV indicates that the project/investment will be profitable (projected earnings generated by the project exceed the anticipated costs), which means that investors should go forward with it. The conclusions of NPV results can be highly sensitive to the parameters assumed (namely the discount rate). Therefore, a sensitivity analysis is performed to better understand how robust the conclusions are.

The methodology applied in this study, both the farm-level impact analysis and the benefit–cost analysis, is based on estimations and assumptions. Even though these estimations and assumptions are based on the most likely scenario, they are still uncertain. For that reason, and following Lubulwa and McMeniman,[41] Macharia *et al.*,[42] Oleke *et al.*[44] and White *et al.*,[46] we perform a sensitivity analysis, which gives an idea of how our conclusions change in adverse and unexpected scenarios.

3 RESULTS AND DISCUSSION

3.1 Farm-level impact analysis

According to the report of Instituto Nacional de Estatística,[51] each kilogram of tomato produced under chemical control conditions is sold by farmers at an average of 0.50 (SP_{CC} = 0.50€). The selling price of biologically controlled tomatoes is higher than the chemical ones by approximately 85%, which results in SP_{BC} = 0.93€ for 1 kg of tomato (this difference is mainly motivated by the lack of supply of biological products when compared to the increasing level of worldwide demand). Concerning the cost of chemical control agents, the market is pricing it at approximately 0.75 €/kg.[52] With this data it is possible to determine the maximum price a farmer is willing to pay for BCA:

$$\begin{gathered} SP_{BC}-SP_{CC}+CC_u>BC_u \quad (3) \\ 0.93€-0.50€+0.75€>BC_u \\ 1.18€>BC_u \end{gathered}$$

From the analysis, we conclude that farmers could have economic benefits by changing from chemical control to biological control practices if the cost of BCA per 1 kg of tomato is lower than 1.18€.

Notice that neither effectiveness rates nor additional production costs of each method are taken into consideration. The reasons for that are the following. First, laboratory studies indicate that BCA have at least the same effectiveness rate as pesticides[9] (even though the first method is a preventive one and the second is a corrective/control one). For that reason, the analysis is conservative by not considering this question. Regarding additional production costs, such as labour inputs, the analysis is also conservative since chemical controls usually require reapplication (more labour inputs), while the benefits of biological control tend to last well beyond the initial investment, even though it takes longer to deliver the desired results.[53]

Current market prices of biological control products against *Tuta absoluta* are 200€ for a 100 mL bottle with 500 biological agents inside (these data were obtained in the webpages of current biofactories). The recommended dosage of application is between 0.25 to 5 biological agents per square metre, depending on pest density. If a preventive procedure is considered, the recommended application is 0.25 agents per square metre in the first week and another identical application 2 weeks later, which represents 0.50 agents per square metre in total (recommended by: https://www.koppert.com/mirical/). Considering that a farmer can produce 10 kg of tomato per square metre, and assuming a preventive release, the current cost for farmers buying BCA is about 0.02€/kg of tomato. Assuming an extreme scenario with high pest density, where the farmer must apply 5 agents per square metre, the cost of buying BCA would be approximately

0.20€/kg of tomato. In both scenarios, the cost is still below the maximum calculated at Eqn (3). These calculations prove that the adoption of biological control practices is profitable for farmers.

In addition to our previous calculations, we must keep in mind how committed governments are to achieve their goals in what concerns organic farming. This means that the implementation of more sustainable agriculture practices, together with the increasing demanding of biological products by consumers, should enhance this market with expectable more profitable revenues to farmers. The total organic area of the EU27 in 2020 (14.7 million hectares) is still small compared with the conventional agricultural systems. Together, France (17.1%), Spain (16.6%), Italy (14.2%), and Germany (10.8%), accounted for well over half (58.7%) of the EU's organic area.[54] Data from 2019 show that only 5.3% of farming in Portugal was organic.[55] Currently, Portugal ranks 11th in terms of area (310,540 ha) and the rate of change between 2012 and 2020 was 59.1%, however, it is still low. The EU has set a goal of 25% of organic farming by 2030.[56] The reason for this low organic area in Portugal is not known at all. One of the possible reasons may result from the absence of public policies with incentives for changing the production model. Indeed, Salavisa *et al*.[55] found that farmers perceive the regulatory framework as unfair relative to that of conventional agriculture. This means that the main question is not how profitable biological control techniques are for farmers. Farmers will have no escape rather than a gradual transition to biological agriculture.

From the analyses earlier, the farm-level impact was based on two main assumptions: (1) the current selling price of biological controlled tomato is approximately 0,93€ for 1 kg of tomato, and (2) the usage of BCA is in a preventive release, which means that the cost is about 0,02€/kg of tomato. At these conditions, we expect that farmers would prefer to change from chemical control practices to biological ones.

Now, we will consider adverse scenarios where: (i) a 20% decrease of the selling price of 1 kg of biological control tomatoes, due to a higher level of biological controlled tomato production (supply and demand theory), (ii) there is a high pest density and, consequently, the cost of BCA would be approximately 0.20€/kg of tomato, (iii) both previous scenarios combined. The results are presented in Table 1. The results show that even under the adverse scenarios considered, it would still be profitable for farmers to change from chemical control practices to biological ones. This means that, in addition to the governmental pressure on farmers to urgently increase the adoption of biological and more sustainable techniques in their crops, these techniques, according to the farm-level impact analysis (partial budgeting method) are profitable (even when considering adverse scenarios). The motivations of farmers are, therefore, not only legal but also economical.

3.2 Benefit–cost analysis (investor/factory perspective)

Any new project/investment starts with the definition of its concept, purpose, and time-horizon. The concept and purpose of the project/investment is the creation of a new factory based in Portugal, dedicated to the production of BCA against tomato moth. Regarding the time-horizon, as in most companies, the principle of continuity is applied. Next, we describe the estimation of inputs and outputs of the project, and the corresponding costs and revenues, to estimate its future CFs and NPV.

The first NPV's projected component is revenues. Current market prices of biological control products against *Tuta absoluta* are approximately 200€ for 500 agents. Under a new project/investment's perspective, with an unsettled and unknown brand among consumers/farmers, a 175€ price for the same number of agents is assumed (sensitivity analysis to these assumptions is performed). According to Instituto Nacional de Estatística,[51] 13 thousand hectares of tomato were produced in 2020, in Portugal. Only approximately 5% of them were organic, i.e., around 650 ha. To achieve the goal of 25% organic farming by 2030, 2,600 more hectares of biological production of tomato are needed. Considering that a preventive application requires 0.5 BCA per square metre, then a total of 13,000,000 BCA per year will be needed to achieve the goal of 25% organic farming. Assuming an objective of 18% market share (a sensitive analysis is performed, considering a market share of 10% instead of 18%), then 2,400,000 BCA will be sold annually. Again, under a new project/investment's perspective, with an unsettled and unknown brand among consumers/farmers, conservative assumptions are made: only 5% of the 2,400,000 BCA are sold in the first year, 15% in the second year, and 35%, 65% and 85% in the third, fourth and fifth year, respectively. From the sixth year on, cruising speed is achieved, i.e., 2,400,000 BCA are sold per year.

The projection of costs is more complex given the diversity of inputs needed to produce BCAs. Operating costs can be divided into three main groups: cost of goods sold and materials consumed; costs with external services and supply; and labour costs. Concerning the cost of goods sold and materials consumed, an estimated cost of 31,594€ (see Table 2) is required for an annual

Table 1. Results for 'farm-level sensitivity analysis'

Scenarios	Base-case	(a)	(b)	(c)
SP_{BC}	0.93€	0.74€	0.93€	0.74€
SP_{CC}	0.50€	0.50€	0.50€	0.50€
CC_u	0.75€	0.75€	0.75€	0.75€
$SP_{BC}-SP_{CC}+CC_u>BC_u$	1.18€>0.02€	0.99€>0.02€	1.18€>0.20€	0.99€>0.20€

Note: The base-case assumes (1) the current selling price of biologically controlled tomato is approximately 0.93€ for 1 kg of tomato; and (2) the usage of biological control agent (BCA) is in a preventive release, which means that the cost is about 0.02€/kg of tomato. Scenario (a) considers a 20% decrease in the selling price of 1 kg of biological control tomatoes, due to a higher level of biologically controlled tomato production (supply and demand theory); Scenario (b) considers a cost of BCA around 0.20€/kg of tomato, in a situation of high pest density. Scenario (c) considers both previous scenarios combined. SP_{BC}, selling price of 1 kg of tomato produced using BCAs; SP_{CC}, selling price of 1 kg of tomato under chemical control; BC_u, cost of biological control agents enough for 1 kg of tomato; CC_u, cost of chemical control agents also enough for 1 kg of tomato.

Table 2. Estimated costs of goods sold and materials consumed (CGSMC)

Cost of goods sold and materials consumed (CGSMC)	For 200,000 agents per month
Tomato seeds	215.86€
Honeydew	5€
Plant substrate	813.74€
Cleaning products	20.8€
Cotton	9.75€
Container (100 mL) for insect's transportation	800€
Shipping costs	50€
Foliar fertilizer	120€
Wood shavings	200€
Labels	50€
Other costs	50€
Protection masks	50€
Ephestia kueniella (eggs) – own/internal production	—
Honeycomb cardboard	200€
Flour – 2.1 kg per card	6€
Carbon dioxide	6.67€
Gel packs to freeze	35€
Total of CGSMC per month	**2,633€**
Total of CGSMC per year	**31,594€**

production of 2,400,000 BCA, where all raw and subsidiary materials are included. Regarding external services and supply, the estimated annual cost is 28,920€ (see Table 3), which includes costs with electricity, water, and gas supply, as well as maintenance and cleaning services, among others. As in revenues, only 5%, 15%, 35%, 65% and 85% of both the cost of goods sold and materials consumed and the cost of external services and supply are considered for the first, second, third, fourth and fifth year, respectively. Please notice that, for simplification purposes, the technological risk and the risk of contaminations (parasites and diseases) were not taken into consideration. Finally, the projected labour cost is approximately 65,000€ annually (see Table 4), corresponding to a total of three workers: a minimum wage worker, a bachelor's degree worker and a PhD worker. In the initial phase, these three workers will have to assume the different responsibilities of the business, such as production, administration (invoicing, payables, etc.), sales, marketing, customer service, etc. If needed, at a late stage, a reanalysis of the model can be performed.

Table 3. Estimated costs of external services and supplies

Services and supplies	Monthly	Annual
Water	60€	720€
Electricity	2,000€	24,000€
Fuel	150€	1,800€
Various	200€	2,400€
Total	**2,410€**	**28,920€**

Note: Transportation/delivery costs are supported by the customer.

Table 4. Estimated labour costs

Number of employees with a doctoral degree	1
Number of employees with a BSc/MSc degree	1
Number of undergraduate employees	1
Gross monthly salary of an employee with a doctoral degree	2,500€
Gross monthly salary of an employee with a with a BSc/MSc degree	1,400€
Gross monthly salary of an undergraduate employee	698.25€
Annual incomes (14 months)	64,375.50€
Social Security costs (23.75%)	15,289.18€
Work insurance (3.19%)	2,053.58€
Total cost	**81,718€**

The initial investment to start this new project plus the needed working capital is roughly 533,000€ (see Table 5), which will be financed through 60% of equity/subsidies and 40% of debt. The main costs of the initial investments are the acquisition of the

Table 5. Estimated initial capital expenditures and working capital

List of items	Total cost
Office supplies	5,000€
Laboratory workbenches	15,000€
Decoration material	5,000€
Car	40,000€
Cost of air conditioning in rearing chambers	25,000€
Sowing trays (54 cells)	300€
Binocular	4,000€
Scale	2,000€
Laboratory chairs	1,200€
Washing room	10,000€
Laboratory material	1,000€
Entomological aspirators	200€
Freezer	2,000€
Printer	100€
Labels printer	250€
Refrigerator	500€
Computers	4,000€
Seedling pots	2,400€
Rearing nets	21,000€
Washing machine	500€
Dryer machine	600€
Corn grinding machine	400€
Ultraviolet sterilizer	200€
Corn thresher	300€
Bio-factory recovery	10,000€
Webpage	5,000€
Ephestia kueniella stack of 24 trays (×10)	38,636.35€
Allotment in an industrial park (400 m^2)	40,000€
Factory construction cost (300 m^2)	255,000€
Total investment	**450,950€**
Total investment	450,950€
Working capital requirements	10,000€
Total investment and working capital requirements	**460,950€**

Table 6. Estimated free cash flow to the firm for the years 2023–2033

Income statement	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Operating income	24,000€	72,000€	168,000€	312 000€	408,000€	480,000€	480,000€	480,000€	480,000€	480,000€	480,000€
Revenues	24,000€	72,000€	168,000€	312,000€	408,000€	480,000€	480,000€	480,000€	480,000€	480,000€	480,000€
Operating expenses	141,113€	147,164€	159,267€	177,421€	189,524€	198,601€	198,601€	198,601€	142,232€	142,232€	142,232€
Cost of goods sold and materials consumed	1580€	4739€	11,058€	20,536€	26,855€	31,594€	31,594€	31,594€	31,594€	31,594€	31,594€
External services and supply	1,446€	4,338€	10,122€	18,798€	24,582€	28,920€	28,920€	28,920€	28,920€	28,920€	28,920€
Labour costs	81,718€	81,718€	81,718€	81,718€	81,718€	81,718€	81,718€	81,718€	81,718€	81,718€	81,718€
Depreciations	56,369€	56,369€	56,369€	56,369€	56,369€	56,369€	56,369€	56,369€	0€	0€	0€
Operating result	−117,113€	−75,164€	8733€	134,579€	218,476€	281,399€	281,399€	281,399€	337,768€	337,768€	337,768€
Financial costs	8413€	6,988€	5523€	4017€	2469€	878€	0€	0€	0€	0€	0€
Stamp tax	337€	280€	221€	161€	99€	35€	0€	0€	0€	0€	0€
Profit before tax	−125,863€	−82,432€	2989€	130,401€	215,908€	280,485€	281,399€	281,399€	337,768€	337,768€	337,768€
Income tax	0€	0€	31,059€	19,169€	31,738€	41,231€	41,366€	41,366€	49,652€	49,652€	49,652€
Profit	−125,863€	−82,432€	−28,069€	111,232€	184,169€	239,254€	240,033€	240,033€	288,116€	288,116€	288,116€
Depreciations	56,369€	56,369€	56,369€	56,369€	56,369€	56,369€	56,369€	56,369€	0€	0€	0€
Financial costs	8,413€	6988€	5523€	4,017€	2469€	878€	0€	0€	0€	0€	0€
Stamp tax	337€	280€	221€	161€	99€	35€	0€	0€	0€	0€	0€
Free cash flow to the firm	−60,744€	−18,795€	34,043€	171,779€	243,106€	296,536€	296,402€	296,402€	288,116€	288,116€	288,116€

factory's building, and its adaptation work, the company's vehicle, and the climate chambers. All these estimated costs are supported by proforma invoices and were estimated after carrying out laboratory experimental studies on the biology and ecology of *M. pygmaeus* and taking into consideration the advice of a manager of a bio-factory. The 40% debt financing consists of a 7-year bank loan with a 1-year grace period and, after that, constant monthly payments of capital and interest. A 2.75% interest rate is assumed, after consulting a local bank. Nevertheless, a sensitive analysis is performed for this parameter, assuming an interest value of 5%.

All factors of Eqn (2) are already estimated (see Table 6) except for *r*, which is the operating CFs discount rate adjusted to the risk of the project. This discount rate is given by the weighted average cost of capital (WACC) represented in Eqn (4):

$$\mathrm{WACC} = \frac{E}{A} \times r_E + \frac{D}{A} \times r_D \times (1 - T_c) \quad (4)$$

Table 7. Discounted cash-flow (DCF) model parameters

Parameters	Values
I_0	533,102€
R_t (annual, at cruising speed)	480,000€
C_t (annual, at cruising speed)	191,884€
FCFF (annual, at cruising speed)	288,116€
r (WACC)	4.34%

Note: I_0 represents the projects' initial investment, and R_t and C_t are the estimated revenues and operating costs at time t, respectively. FCFF stands for the 'free cash flow to the firm' and the risk rate to discount the cash flows to time 0 is given by r, calculated using the weighted average cost of capital (WACC).

where $\frac{E}{A}$ is 60%, which represents the weight of equity (E) in total assets (A), $\frac{D}{A}$ is 40%, which represents the weight of debt (D) in total assets (A), r_D stands for the cost of debt (2.75% interest rate), and T_c the current tax rate for corporations (16.1%). Regarding r_E, it reflects the return required by equity investors in the project. This return can be determined using the well-known capital asset pricing model (CAPM) from Merton[57]:

$$r_E = r_f + \beta (r_m - r_f) \quad (5)$$

Table 8. Weighted average cost of capital (WACC) and capital asset pricing model (CAPM) calculations

CAPM		WACC	
r_f	1.40%	E/A	60%
r_m	8.20%	D/A	40%
β	0.88	r_E	7.38%
CAPM	**7.38%**	r_D	2.75%
		T_c	16.1%
		WACC	**4.34%**

Note: r_f is the risk-free rate, r_m is the expected market return and β is the beta of the investment. Both r_f (1.40%) and r_m (8.20%) are obtained from Fernandez *et al.*[58] Regarding β, and according to Damodaran,[59] the unlevered beta of investments in biotechnology is 0.89, while investments in farming/agriculture have an unlevered beta of 0.87. A simple average of both results in a β of 0.88. Using the CAPM model, a r_E of 7.38% is obtained, which represents the return required by equity investors in the project. $\frac{E}{A}$ represents the weight of equity (E) in total assets (A), $\frac{D}{A}$ represents the weight of debt (D) in total assets (A), r_D stands for the cost of debt and T_c the current tax rate for corporations.

Table 9. Net Present value (NPV), internal rate of return (IRR) and payback results

Variable	Result
NPV	7.2 million euros
IRR	28.40%
Payback period	5 years and 4 months

where r_f is the risk-free rate, r_m is the expected market return and β is the beta of the investment. Both r_f (1.40%) and r_m (8.20%) are obtained from Fernandez *et al.*[58] Regarding β, and according to Damodaran,[59] the unlevered beta of investments in biotechnology is 0.89, while investments in farming/agriculture have an unlevered beta of 0.87. Therefore, a simple average of both is considered, resulting in a β of 0.88. Considering all these values, an r_E of 7.38% is obtained. This result contributes to the existing literature that finds it difficult to achieving a consensus about the discount rate to apply on these projects.[60] Table 7 shows the DCF model parameters and Table 8 the WACC and CAPM calculations.

Having r_E calculated, the resulting WACC is 4.34%. This is the discount rate that will be applied to the operating CFs in Eqn (2), leading to a positive NPV of the project of 7.2 million euros. This positive NPV indicates that the discounted present value of all future CFs related to the project are positive and higher than the initial investment in 7.2 million euros and, therefore, attractive, economically, and financially viable. The payback period for a brand-new factory is 5 years and 4 months. It means that it takes 5 years and 4 months for the project to recover the cost of the investment.

Another metric to evaluate a project is the internal rate of return (IRR),[61] given by Eqn (6):

$$0 = -I_0 + \sum_{t=1}^{\infty} \frac{(R_t - C_t)}{(1+\mathrm{IRR})^t} \quad (6)$$

where IRR is seen as a 'breakeven rate' which makes the projects' NPV equal to zero. The IRR is usually compared to the discount rate r. If the former is greater than the later, projects are economically and financially profitable.

Using Excel's add-in solver, a project's IRR of 28.40% is obtained. This return, compared to the 4.34% WACC, shows again that the project is economically and financially viable and investors should go forward with it. All estimations and calculations performed in this study are conservative, a reason why a reasonable IRR of 28.40% is obtained. Other identical studies in the literature estimate much higher IRR. For example, Aidoo *et al.*[62] estimated an IRR of 1740% under a worst-case scenario for biological control of cassava green mite in Ghana. Our results are in line with most of the existing literature when concluding that new projects on BCAs' production are clearly worth the investment. Table 9 resumes the NPV, IRR and payback results.

For the DCF sensitivity analysis, a stress test is performed for the main dimensions of the model, namely: (i) a 20% increase on the cost of the initial investment, (ii) a 20% decrease on the projected sales, (iii) a 20% increase on the cost of inputs, such as the cost of goods sold and materials consumed, external services and supply, and labour costs, (iv) all previous scenarios combined, (v) a market share of 10% instead of 18% and (vi) an interest rate of 5% instead of 2.75%. For each of these scenarios, the NPV and IRR are re-calculated, providing information about the attractiveness and economic feasibility of the project under stress situations. The results are presented in Table 10. In all the stressed scenarios tested, the project still has a positive (and significant) NPV, as well as an IRR higher than the WACC. This means that the project is economically and financially viable, representing a valuable investment for potential investors. These results are not surprising, given other identical studies in the literature with much higher NPV and IRR.

Market value of BCAs depends on its market demand. *Macrolophus pygmaeus* was ranked as the seventh most important invertebrate biological control[63] and its market value was labelled 'large' once hundred thousand to millions of individuals were sold per week.[21] However, in a later study *M. pygmaeus* were no longer included in the earlier-mentioned lists.[9] In the opposite direction, appears *Trichogramma achaeae*. While not included in the study of van Lenteren *et al.*,[21] it later appears[9] as a valuable natural enemy of lepidopterans pests, commercialized in Europe for the first time in 2012, and having a market value rated of 'medium' due to 10,000 to a 100,000 individuals sold per week. The shift of the commercial importance of *Trichogramma achaeae* and the increasing number of scientific studies using *M. pygmaeus* as model pest species[25,33,64,65] may have been a consequence of the invasion of Europe by *Tuta absoluta*, a major pest of tomato crops.[10] The current major concerns with *Tuta absoluta* together with the increase of scientific research, makes its natural enemies valuables market products for the near future.

Table 10. Results for 'investor-level sensitivity analysis'

Scenarios	Base-case	(a)	(b)	(c)	(d)	(e)	(f)
NPV	7.2 million euros	7.1 million euros	5.0 million euros	6.5 million euros	4.2 million euros	2.3 million euros	4.9 million euros
IRR	28.40%	25.96%	22.72%	25.96%	18.34%	14.08%	28.39%

Note: NPV stands for net present value of the project and IRR for internal rate of return of the project. Stress tests are performed to the base-case scenario, where (a) a 20% increase on the cost of the initial investment is considered; (b) a 20% decrease on the projected sales is considered; (c) a 20% increase on the cost of inputs, such as the cost of goods sold and materials consumed, external services and supply, and labour costs, is considered; (d) all previous scenarios combined is considered; (e) a market share of 10% instead of 18% is considered; and (f) an interest rate of 5% instead of 2.75% is considered.

Pest Management Science published by John Wiley & Sons Ltd on behalf of Society of Chemical Industry.

4 CONCLUSION

The aim of this study was to develop an economic and financial model to evaluate the commercial viability of mass production of *M. pygmaeus* against tomato moth in protected culture. For this, two approaches were considered, the farm-level impact analysis and the benefit–cost analysis. Our study is in line with the most current legislation which imposes the shift of the agricultural practices based on chemical control of the phytophagous pests to more environmental and economic management practices, the use of BCAs. The application of the farm-level and the benefit–cost analysis to access the economic and financial viability of the implementation of a bio-factory in the Azores allowed us to conclude that the mass-rearing of *M. pygmaeus* to control the moth *Tuta absoluta* in protected culture practices can be profitable for farmers and that the overall project of investing in a bio-factory is also profitable, no matter how we stress up the model with changes in costs, revenues and prices. Given the first conclusion that it is profitable for farmers to change from chemical control practices to biological ones, a DCF analysis was performed and an NPV and IRR of 7.2 million euros and 28.40%, respectively, were achieved for the base-case scenario. Although the models are not static, due to changes in the context, there is still a wide margin to accommodate changes in different variables.

AUTHOR CONTRIBUTIONS

TMD, MGB, JCAT, ST, MLO, JT, IB, AOS all provide data to develop the economic and financial model, wrote the manuscript and provided critical feedback.

FUNDING INFORMATION

This study was financed by FEDER in 85% and by Azorean Public funds by 15% through Operational Programme Azores 2020, under the following project: ECO^2 – TUTA (ACORES-01-0145-FEDER-000081). Luísa Oliveira was funded by Portuguese national funds FCT under the project UIDP/05292/2020 and UIDB/05292/2020.

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings will be available in Repositório da Universidade dos Açores at [DOI/URL] following an embargo from the date of publication to allow for commercialization of research findings.

REFERENCES

1 REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on the sustainable use of plant protection products and amending Regulation (EU) 2021/2115. 71pp.
2 OJ L 309, 24.11.2009, p. 71–86 (EN) http://data.europa.eu/eli/dir/2009/128/oj.
3 Cock MJW, Murphy ST, Kairo MTK, Thompson E, Murphy RJ and Francis AW, Trends in the classical biological control of insect pests by insects: an update of the BIOCAT database. *BioControl* **61**:349–363 (2016).
4 Rondoni G, Borges I, Collatz J, Conti E, Costamagna AC, Dumont F *et al.*, Exotic ladybirds for biological control of herbivorous insects – a review. *Entomol Exp App* **169**:6–27 (2021).
5 Soares AO, Honek A, Martinkova Z, Brown PM and Borges I, Can native geographical range, dispersal ability and development rates predict the successful establishment of alien ladybird (Coleoptera: Coccinellidae) species in Europe? *Front Ecol Evol* **6**:57 (2018).
6 Soares AO, Haelewaters D, Ameixa OMCC, Borges I, Brown PMJ, Cardoso P *et al.*, A roadmap for ladybird conservation and recovery. *Conserv Biol* **37**:e13965 (2023).
7 Francuski L and Beukeboom LW, Insects in production – an introduction. *Entomol Exp Appl* **168**:6–7 (2020).
8 Sørensen JG, Addison MF and Terblanche JS, Mass-rearing of insects for pest management: Challenges, synergies and advances from evolutionary physiology. *Crop Prot* **38**:87–94 (2012).
9 van Lenteren JC, Bolckmans K, Keohl J, Ravensberg WJ and Urbaneja A, Biological control using invertebrates and microorganisms: plenty of new opportunities. *BioControl* **63**:39–59 (2018).
10 Biondi A, Guedes RNC, Wan F-H and Desneux N, Ecology, worldwide spread, and management of the invasive south American tomato pinworm, *Tuta absoluta*: past, present, and future. *Annu Rev Entomol* **63**:239–258 (2018).
11 Desneux N, Wajnberg E, Wyckhuys KAG, Burgio G, Arpaia S, Narváez-Vasquez CA *et al.*, Biological invasion of European tomato crops by *Tuta absoluta*: ecology, geographic expansion and prospects for biological control. *J Pest Sci* **83**:197–215 (2010).
12 Desneux N, Luna MG, Guillemaud T and Urbaneja A, The invasive South American tomato pinworm, *Tuta absoluta*, continues to spread in Afro-Eurasia and beyond: the new threat to tomato world production. *J Pest Sci* **84**:403–408 (2011).
13 El Kichaoui A, El-Shafai A, Muheisen H, Mosleh F and El Hindi MW, Safe approach to the biological control of the Tomato Leafminer *Tuta absoluta* by entamopathogenic fungi *Beauveria bassiana* isolates from Gaza Strip. *Int J App Res* **2**:351–355 (2016).
14 Coelho MCF and França FH, Biologia, quetotaxia da larva e descrição da pupa e adulto da traça-do-tomateiro. *Pesquisa Agropecuária Brasil* **22**:129–135 (1987).
15 García MF and Espul JC, Bioecology of the tomato moth (*Scrobipalpula absoluta*) in Mendoza, Argentine Republic. *Rev Invest Agrop* **17**:135–146 (1982).
16 Chailleux A, Bearez P, Pizzol J, Amiens-Desneux E, Ramirez-Romero R and Desneux N, Potential for combined use of parasitoids and generalist predators for biological control of the key invasive tomato pest *Tuta absoluta*. *J Pest Sci* **86**:533–541 (2013).
17 Gervassio NGS, Luna MG, D'Auro F and Sánchez NE, Performance of *Pseudapanteles dignus* (Hymenoptera: Braconidae), a natural enemy of *Tuta absoluta* (Lepidoptera: Gelechiidae) in eggplant. *J Econ Entomol* **111**:528–532 (2018).
18 Luna MG, Sánchez NE, Pereyra PC, Nieves E, Savino V, Luft E *et al.*, Biological control of *Tuta absoluta* in Argentina and Italy: evaluation of indigenous insects as natural enemies. *Bulletin OEPP/EPPO* **42**:260–267 (2012).
19 Zappalà L, Bernardo U, Biondi A, Cocco A, Deliperi S, Delrio G *et al.*, Torpea Garzia and Siscaro, G, Recruitment of native parasitoids by the exotic pest *Tuta absoluta* in Southern Italy. *Bull Insec* **65**:51–61 (2012).
20 Zlof V and Suffert M, Report of the EPPO/FAO/IOBC/NEPPO Joint International Symposium on management of *Tuta absoluta* (tomato borer). *Bull OEPP/EPPO Bull* **42**:203–204 (2012).
21 van Lenteren JC, The state of commercial augmentative biological control: plenty of natural enemies, but a frustrating lack of uptake. *BioControl* **57**:1–20 (2012).
22 Global Market Insights, Biocontrol Agents Market (Report ID: GMI1551) (2019). https://www.gminsights.com/industry-analysis/biocontrol-agents-market.
23 Oliveira L, Durão A, Fontes F, Roja IS and Tavares J, Potential of *Trichogramma achaeae* (Hymenoptera: Trichogrammatidae) in biological control of *Tuta absoluta* (Lepidoptera: Gelechiidae) in Azorean greenhouse tomato crops. *J Econ Entomol* **110**:2010–2015 (2017).
24 Alvarado P, Balta O and Alomar O, Efficiency of four heteroptera as predatorsof *Aphis gossypii* and *Macrosiphum euphorbiae* (*Hom.: Aphididae*). *Entomophaga* **42**:215–226 (1997).
25 Arnó J, Castañé C, Riudavets J and Gabarra R, Risk of damage to tomato crops by the generalist zoophytophagous predator *Nesidiocoris tenuis* (Reuter) (Hemiptera: Miridae). *Bull Ent Res* **100**:105–115 (2009).
26 Barnadas I, Gabarra R and Albajes R, Predatory capacity of two mirid bugs preying on *Bemisia tabaci*. *Entomol Exp Appl* **86**:215–219 (1998).

27 Calvo J, Blockmans K, Stansly PA and Urbaneja A, Predation by *Nesidiocoris tenuis* on *Bemisia tabaci* and injury to tomato. *Biocontrol* **54**: 237–246 (2009).
28 Castañé C, Arnó J, Gabarra R and Alomar O, Plant damage to vegetable crops by zoophytophagous mirid predators. *Biol Control* **59**:22–29 (2011).
29 Fauvel G, Malausa JC and Kaspar B, Étude en laboratoire des principales caractéristiques biologiques de *Macrolophus caliginosus* [Heteroptera: Miridae]. *Entomophaga* **35**:529–543 (1987).
30 Margaritopoulos JT, Tsitsipis JA and Perdikis DC, Biological characteristics of the mirids *Macrolophus costalis* and *Macrolophus pygmaeus* preying on the tobacco form of *Myzus persicae* (Hemiptera: Aphididae). *Bull Ent Res* **93**:39–45 (2003).
31 Perdikis D, Kapaxidi E and Papadoulis G, Biological control of insect and mite pests in greenhouse solanaceous crops. *Eur J Plant Sc Biot* **2**:125–144 (2008).
32 Riudavets J and Castañé C, Identification and evaluation of native predators of *Frankliniella occidentalis* (Thysanoptera: Thripidae) in the Mediterranean. *Env Ent* **27**:86–93 (1998).
33 Urbaneja A, Montón H and Mollá O, Suitability of the tomato borer *Tuta absoluta* as prey for *Macrolophus pygmaeus* and *Nesidiocoris tenuis*. *J App Ent* **133**:292–296 (2009).
34 Urbaneja A, Gonzalez-Cabrera J, Arno J and Gabarra R, Prospects for the biological control of *Tuta absoluta* in tomatoes of the Mediterranean basin. *Pest Manag Sci* **68**:1215–1222 (2012).
35 Borges I, Oliveira L, Durão AC, Arruda P, Figueiredo E, Franco JC *et al*., Contrasting phenotypic variability of life-history traits of two feral populations of *Macrolophus pygmaeus* (Hemiptera: Miridae) under two alternative diets. *Agronomy* **13**:118 (2023).
36 Cullen R, Warner KD, Jonsson M and Wratten SD, Economics and adoption of conservation biological control. *Biol Control* **45**:272–280 (2008).
37 Waterfield G and Zilberman D, Pest management in food systems: an economic perspective. *Annu Rev Env Resour* **37**:223–245 (2012).
38 Naranjo SE, Ellsworth PC and Frisvold GB, Economic value of biological control in integrated pest management of managed plant systems. *Annu Rev Entomol* **60**:621–645 (2015).
39 Naranjo SE, Frisvold GB and Ellsworth PC, Economic Value of Arthropod Biological Control, in *The Economics of Integrated Pest Management of Insects*, ed. by Onstad DW and Crain PR. *CAB International*; Wallingford, UK, pp. 49–85 (2019).
40 Letourneau D, Ando A, Jedlicka J, Narwani A and Barbier E, Simple-but-sound methods for estimating the value of changes in biodiversity for biological pest control in agriculture. *Ecol Econ* **120**:215–225 (2015).
41 Lubulwa G and McMeniman S, An Economic Evaluation of Realised and Potential Impacts of 15 of ACIAR's Biological Control Projects (1983–1996): Some Preliminary Estimates. 136244, in *1997 Conference (41st), January 22–24, 1997, Gold Coast, Australia*. Australian Agricultural and Resource Economics Society, Australia (1997).
42 Macharia I, Lohr B and De Groote H, Assessing the potential impact of biological control of *Plutella xylostella* (diamondback moth) in cabbage production in Kenya. *Crop Prot* **24**:981–989 (2005).
43 Myrick S, Norton G, Selvaraj K, Natarajan K and Muniappan R, Economic impact of classical biological control of papaya mealybug in India. *J Crop Prot* **56**:82–86 (2014).
44 Oleke JM, Manyong V, Mignouna D, Isinika A, Mutabazi K, Hanna R *et al*., Ex-ante economic analysis of biological control of coconut mite in Benin. *AgBioForum* **16**:161–169 (2013).
45 Waterhouse D, Dillon B and Vincent D, Economic benefits to Papua New Guinea and Australia from the biological control of the banana skipper (Erionota thrax), in *ACIAR Project CS2/1988/002-C*. ACIAR, Canberra (1998).
46 White JM, Allen PG, Moffitt LJ and Kingsley PP, Economic analysis of an area-wide program for biological control of the alfalfa weevil. *Am J Alt Agric* **10**:173–179 (1995).
47 Zhang H, Garratt MPD, Bailey A, Potts SG and Breeze T, Economic valuation of natural pest control of the summer grain aphid in wheat in Southeast England. *Ecos Serv* **30**:149–157 (2018).
48 Hill G and Greathead DJ, Economic evaluations in classical biological control: The Economics of Biological Invasions, in, ed. by Perring C, Williamson M and Dalmazzone S. Edward Elgar, Cheltenham, UK, pp. 208–223 (000).
49 Kabaale FP, Tumuhaise V, Tinzaara W, Turyasingura G, Subramanian S, Khamis FM *et al*., First report of field efficacy and economic viability of *Metarhizium anisopliae*-ICIPE 20 for *Tuta absoluta* (Lepidoptera: Gelechiidae) management on tomato. *Sustainability* **14**:4846 (2022).
50 Copeland TE, Weston JF and Sastri K, *Financial Theory and Corporate Policy*, fourth edn. Pearson New International Edition, Essex, UK, (2014).
51 INE – Instituto Nacional de Estatística, Estatísticas Agrícolas (2020).
52 Koppert, 2021. https://www.koppert.com/news/2021/stepping-up-the-fight-against-tuta-absoluta-in-kenya-with-safer-and-sustainable-biocontrol-products/
53 Kortam MN, *Biological control of certain greenhouse pests*. Ph.D. thesis. Faculty of Agriculture, Cairo University, Cairo, Egypt, (2019).
54 EUROSTAT Organic Farming Statistics. Available online: https://ec.europa.eu/eurostat/statistics-explained/index.php/Organic_farming_statistics (accessed on 28 December 2022).
55 Salavisa I, Ferreiro MF and Bizarro S, The transition of the agro-food system: lessons from organic farming in the Lisbon metropolitan area. *Sustainability* **13**:9495 (2021).
56 European Commission. Action Plan for the future of Organic Production in the European Union 2014. Available online: https://ec.europa.eu/commission/presscorner/detail/en/IP_21_1275 (accessed on 28 December 2022).
57 Merton RC, An Intertemporal Capital Asset Pricing Model. *Econometrica* **41**:867–877 (1973).
58 Fernandez P, Bañuls S and Fernandez Acin P, Survey: Market risk premium and risk-free rate used for 88 countries in 2021. *IESE Business School Working Paper* 1–17 (2021).
59 Damodaran A, *Levered and Unlevered Betas by Industry*. New York University, Stern School of Business. https://pages.stern.nyu.edu/~adamodar/New_Home_Page/datacurrent.html, (2022).
60 Field BC and Field MK, *Environmental Economics: An Introduction*, fourth edn. McGraw-Hill Irwin, Boston, MA (2006).
61 Napit KB, Norton GW, Kazmierczak RFJ and Rajotte EG, Economic impacts of extension integrated pest management programs in several states. *J Econ Ent* **81**:251–256 (1988).
62 Aidoo R, Osekre EA, Logah V and Andivi Bakang JE, Economic benefits of biological control of cassava green mite (CGM) in Ghana. *J Dev Agri Econ* **8**:172–185 (2016).
63 Cock MJW, van Lenteren JC, Brodeur J, Barratt BIP, Bigler F, Bolckmans K *et al*., Do new access and benefit sharing procedures under the convention on biological diversity threaten the future of biological control? *BioControl* **55**:199–218 (2010).
64 Arnó J, Molina P, Aparicio Y, Denis C, Gabarra R and Riudavets J, Natural enemies associated with *Tuta absoluta* and functional biodiversity in vegetable crops. *BioControl* **66**:613–623 (2021).
65 CABI, *Tuta absoluta*. http://www.https://www.cabi.org/isc/datasheet/49260 (2022).