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SCIENTIFIC NOTE

Integrated Pest Management Education: a Video-Game to Improve Management of *Drosophila suzukii*, Soft-Skin Fruit Pest

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Abstract
The transition from the conventional global agriculture to an agroecological model poses a teaching and learning challenge to facilitate the wide variety of practices and the many biological processes involved. Games, such as board games, video-games, or mobile apps, are elements that may be used for teaching agroecology, environmental education, or animal conservation. Here, we present a video-game designed to contribute to integrated pest management education. The Spotted-Stop-It video-game is a single-player game which encourages participation, disseminates knowledge on the pest problem and its potential solutions (i.e., harvest frequency, sanitation, and management of alternative non-crop plants), and highlights the importance of good practices from an agroecological perspective at the farmer scale. In a farm-tech regional fair, we presented the game to its users and performed a simple retrospective survey. The survey results showed that most participants did not know about the fly prior to playing the game (34 ind., 68%), but were able to recognize the species among other flies after playing (23 ind., ~ 65%). Also, 21 individuals correctly responded about the effects of this pest on soft-skin fruits ("the fly lays eggs inside the fruit"). The training of future generations on new insect invasions and IPM practices with elements of their own environment may prove to be important to transmit concepts and practices at the service of sustainable crop protection.

Keywords Spotted wing Drosophila · Outreach · IPM education

Introduction

Over the years, stakeholders of agricultural systems, such as farmers, basic and applied scientists, and consumers, have called for alternative methods for food production, although the standing paradigm of conventional agriculture still dominates most academic and policy discussions (Valenzuela 2016). However in recent years, an emerging model for global agriculture—agroecology—has had some strong advocates in many communities, although the transition from conventional agriculture to an agroecological approach is yet to be fully understood (Zhaochang 2018). Agroecology is defined as an integrated approach which applies ecological and social concepts to the management of sustainable agriculture (Specht et al. 2022). The use of insecticides in agriculture is a key issue to be solved, and the degree of public intervention in farmer advising and the educational paradigm strongly influence whether pesticides are used or not and how well is an agroecological approach adopted (Wuepper et al. 2021). Thus, any transition from an orthodox, industrial agriculture to a more sustainable food production process has an important teaching and learning challenge aimed at facilitating access to the wide variety of practices available and to the dominant many social and biological processes influencing pest impact (Jouan et al. 2020).

Even though digital games are considered by most only a means for entertainment, nowadays, this perception is moving in unexpected directions. As well as allowing to simulate different realities used for instance in training airplane pilots or law-enforcement agents, digital game technology has become the focus of study in different fields of science and approached as a tool in outreach activities (Pontuschka et al. 2012). In this sense, new games have emerged as effective and highly motivational educational tools for learning and teaching in a great variety of fields (Calvo-Morata et al. 2020). Examples of games

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Harvested Fruits: 4
Attacked Fruits: 2
A
B
C
D
E
Drosophila suzukii is a pest that affects raspberry, cherry, strawberry, blueberry and other thin-skinned crops. This insect has a very short life cycle and can lay many eggs in one season. It is a very small fly that measures between 2 and 3 mm. Males differ from females as they can be identified by a dark spot on the wing. The females have a serrated ovipositor that allows them to cut the skin of the fruit and lay the eggs.
PLAY

◂**Fig. 1** Protagonists of the Spotted-Stop-It video-game. **A** Female and male of *Drosophila suzukii* (spotted wing Drosophila). **B** Farmer. **C** Fruits represented in the game: main crop fruit (raspberries, blueberries, strawberries); wild fruit; and dropped fruit. **D** Student playing with mobile app. **E** Screen from Spotted-Stop-It with real photos and cartoons to represent the male and female fly

with the aim to improve the process of learning agroecology (SEGEA, Jouan et al. 2020) or environmental education (EcoDragons, Khelifa and Mahdjoub 2021) or animal conservation (Animal Crossing: New Horizons, Fisher et al. 2021) have been very recently developed.

Learning and teaching pest management to the broader public is of paramount importance, given the need not only for the development but, more importantly, for the appropriation of sustainable practices. This is because the activity which focuses on reducing the reportedly high losses to pests in staple food production is driven largely by the private sector, especially in developing economies (Deguine et al 2021). Due to the fact that pests are often invasive species, the involvement of the general public may prove crucial to impede their arrival and establishment.

The spotted wing Drosophila (SWD) (*Drosophila suzukii*; Matsumura; Diptera: Drosophilidae) is a soft-skin fruit pest that has invaded many regions of the world. This highly invasive fly native to eastern Asia was detected in Europe and North America in 2008 (Cini et al. 2012) and spread widely in South America between 2012 and 2015 (de la Vega and Corley 2019; de la Vega et al. 2020). The main problem is caused by females that lay eggs in undamaged fresh and ripening highly priced soft-skin fruits such as cherries and berry crops (i.e., raspberries, blueberries, and strawberries) (Bolda et al. 2010; Walsh et al. 2011). Because of their nature and commercial routes, many traditional pest management interventions for these crops, such as the use of pesticides, have become problematic (Haviland and Beers 2012; VanWoerkom et al. 2022).

Given its known track record, once this invasive insect arrives to a new region, a large amount of local research effort is directed towards mitigation of the problem, including studies about its biology, distribution, and local management procedures (Lee et al. 2011a, b). Currently, a good amount of information has been collected throughout the invaded range and different pest management programs are being implemented—mostly through governmental intervention—in many regions, although broad ranging, sustainable success is yet to be achieved. A critical step appears to be how to manage and curate all of this new, local information and how to efficiently disseminate it through outreach programs aimed at the public and stakeholders in order to involve them in the management of this pest problem (Lee et al. 2011a, b).

Here, we introduce a video-game we have developed, as a tool for education and outreach objectives aimed at improving sustainable management practices of SWD. The "Spotted-Stop-It" game is a free downloadable game stored at the website of Insect Population Ecology Group (GEPI, in Spanish) (https://sites.google.com/site/gepinsectos/publicaciones/divulgacion/juegos?authuser=0). The aim of the game is to encourage participation, disseminate knowledge on the pest problem and solutions for it (i.e., harvest frequency, sanitation, and management of alternative non-crops), and highlight the importance of good practices from an agroecological perspective to minimize pest damage at the farmer scale.

Game description

The "Spotted-Stop-It" video-game was developed in the open-source cross-platform creator Gdevelop (Gdevelop5, 2020). It has two screens before the game starts, the first one, showing three essential components of the integrated pest management plan for SWD in raspberries and with small fruits such as harvest frequency, sanitation, and management of alternative hosts. The second screen is a brief description of the male and female fly. Regarding the first screen, the aim of the three components is to reduce habitat availability for SWD oviposition. Despite the fact that *D. suzukii* prefers undamaged fruits, the use of alternative hosts as reservoirs, such as non-crop fruits and fallen fruit, favors the spread and population growth of the pest, hence its damage to crops (Walsh et al. 2011). Increasing the harvest frequency is a simple strategy in an IPM model, consisting in reducing the harvest interval of raspberries to, at least, 2 days in order to decrease the prevalence of SWD larvae without decreasing the marketable yield (Leach et al. 2018). Also, sanitation by the removal of dropped, wasted, or fallen berries and bagging solarization or burying them decreases habitat suitability for this fly (Haye et al. 2016, Hooper and Grieshop 2020). The third component, the management of non-crops, includes wild and ornamental plants which could act as alternative hosts when the main crops are less available (Kenis et al. 2016). It is important to know that alternative hosts and non-crops can also serve as a refuge from chemical applications and extreme climate conditions. Moreover, they have an important role in the pest population dynamics in the landscape, where cultural control tactics for reducing populations could also be applied (Lee et al. 2015). It has been suggested that these three methods, involved in altering resource availability, should be combined with other cultural practices to reduce the suitability of crop habitats for this invasive pest (Schöneberg et al. 2021).

The second screen of the video-game shows a description of the SWD. We summarize the biology of the pest

pointing to the main crops affected (raspberries, cherries, strawberries, and blueberries) and its life cycle, mainly presenting how to identify both males and females and the size of the fly. We added two real-life photographs and the caricaturized versions used in the game to represent both sexes (Fig. 1E). Combining real photographs with cartoons is an important point to help users or gamers link the game to reality. Also, pictures of the fly were taken on a blueberry, which acts as a scale gauge, as it represents the actual size of the flies and how they attack fruits in real is a key aspect for improved pest management. For example, a first point raised in the program evaluation of the collaborative workforce from USA, the "SWD*IPM"—likely one of the main programs deployed worldwide for the management for SWD after first detections in 2009—was to identify and disseminate biological and management knowledge. The identification of a new, invasive pest insect is often difficult and efforts should be focused on helping users to properly identify it, understand its potential impact, and adopt management practices (Dreves 2011).

Game characters

The video-game has three main characters: flies, a farmer, and fruits. Regarding flies, both female and the male flies were drawn. The agricultural problem and the attack to the fruit are produced by the female, since they have a serrated ovipositor to penetrate and lay eggs inside soft-skinned fruit (Lee et al. 2011a, b). However, males are more easily identified than females, due to their conspicuous black spots on the wings and the two sets of black tarsal combs (Hauser 2011). In the outreach literature, SWD is mainly represented by the male because of the relative ease of identification, although, as the main problem is generated by the female, both sexes are represented in the game and they have different actions (Fig. 1A).

In order to avoid pronouns that demonstrate stereotypical representations (Heritage 2021), the second character is a genderless farmer. All the video-game was developed taking into account aspects of ethics, including conscious avoidance of any gender or racist implications (Fig. 1B). The third character is the fruit. We represented raspberries, blueberries, and strawberries as the fly's preferred hosts and wild fruits, as non-crop alternative hosts. We also drew dropped versions of raspberries, blueberries, and strawberries which act as reservoirs (Fig. 1C). In this sense, both kinds of fruit, fallen and fresh fruits hanging from the plants (crops and non-crops), represent the niche exploited by SWD where it avoids its competitors and natural enemies, and consequently increases its performance in an invaded area (Poyet et al. 2015).

Game objective and rules

The "Spotted-Stop-It" video-game is a single-player game where the players control farmer's movements in four directions. The player's "farm" is a simple agricultural environment representing small growers or family-farmers, depicted as less than one hectare large farm. It has movement obstacles and is limited by fences and shrubs for the farmer but not for the flies. The aim of the game is to collect the raspberry, strawberry, and blueberry crops before the population of SWD gets unmanageable. In order to achieve this, the farmer must harvest 50 fresh fruits as fast as possible before the population of SWD attacks 20 fruits. SWD can attack fallen fruits, non-crop fruits, and also the main crops. Specifically, every time the female fly touches any fruit, the fruit disappears and adds one point in favor to the fly's counter. As in the field, only females attack and hence add new attacked fruits to the counter. In the game, both female and male move randomly in every direction and velocity, although we represented the female as more active. In those random movements, if a female and a male fly meet at the same position at the same time over a fallen or a non-crop fruit, the fly reproduces.

Relevance to integrated pest management outreach

Science communication is an essential step in the implementation of an idea of integrated pest management for the general public or for public health educational of integrated vector management (Bartlett-Healy, et al. 2011). Public education in pest management involves tools aimed for all stages, from elementary school levels to adult outreach programs, and may include flyers, videos, insect tracking maps, or children's websites with games (Fonseca et al. 2013). Serious games are a tool often deployed for children and adolescents, and their aim is to cultivate their knowledge and practice their skills, with effective learning outcomes and personal and social development (Campo and Dangles 2020). Examples of video-games used for public outreach are those of the National Pest Management Association (NPMA) for children (PestWorldForKids.org), the newly EcoDragons (Khelifa and Mahdjoub 2021), or SEGEA gameplay (Jouan et al. 2020). These kinds of games could facilitate learners' holistic understanding of scientific concepts.

Even though there has been reports of undesirable aspects of games used in education which could aggravate the mental workload and, therefore, generate a decrease in learning effectiveness, well-designed games may prove to be effective in enhancing cognitive abilities (Campo and Dangles 2020). New educational technologies, such as mobile applications,

have improved learners' academic achievements and encourage their participation in learning activities (Zhonggen 2019). In this sense, the "Spotted-Stop-It" game we introduce here is an opportunity for teachers and science communicators to show the beneficial impacts of agroecological practices. Environmental education using a game is a playful means for showing ecological concepts which could reach a larger audience, including children (Khelifa and Mahdjoub 2021). The training of future generations in good agroecological practices with elements of their own knowledge, as "Spotted-Stop-It," could be a great opportunity to provide a flexible learning of integrated pest management issues (Fig. 1D). Also, since it was created in an open-source platform, it could be rapidly adapted using other invasive pest species as main characters.

Presenting the video-game to the public

We presented the video-game for the visitors and performed a simple retrospective survey in an agri-science exhibition and fair, the "Expo Rural Bariloche," held on February 18 to 20, 2022 (Mat. Supp. S1 and Table 1). We invited visitors or all ages to play the game at our stand and after playing, we asked them about their prior knowledge of SWD. Then we invited them to recognize SWD from 4 photographs of different fly species. In the questionnaire, we also asked about the effect of SWD in soft-skin fruit production and which of the agroecological techniques had been performed in the video-game (whether it was increasing the harvest frequency; sanitation; management of alternative hosts or all of them). These two last questions are agroecological issues which did not imply the visual recognition of the fly nor personal background information. In this sense, they had the abstract concepts, such as "oviposition inside the fruit" or "harvest frequency," only shown as text on the introductory screens, or experimented by the visitors during the gameplay or explained verbally, depending on the age of the player.

Most of the visitors were children from 5 to 13 years old (min = 5, Q1 = 10, Q2 = 13, mean = 20, Q3 = 31, max = 61). The questionnaire showed that despite the fact that most participants did not know about the fly prior to playing the game (34 ind., 68%), they could recognize the SWD from other flies after (23 ind., ~ 65%). Also, 21 individuals answered about the effect in the soft-skin fruits ("the fly lais the eggs inside the fruit") correctly (Table 1, Fig. 2). For the last question regarding the management practices applied in the game, most participants were able to identify that the harvest frequency, sanitation, and management of alternative hosts were present while playing (Table 1).

Perspective

The "Spotted-Stop-It" is a downloadable gameplay and freely available to play online. Here, we present a version with only three levels, but that may include more levels in the future. Adding increasing levels of difficulty and different tools for management the SWD, such as (1) using parasitoids (taking into account imported or local populations), (2) deploying different types of traps, and (3) the use of the sterile insect technique — where if irradiated males, and therefore sterile ones, moving randomly collide with females, these last flies would be unable to attack fruits. Also, in order to be adapted and adopted in different regions

Table 1 Results from 47 responses in the presentation of the Spotted-Stop-It video-game

Questions	Answers	Choice percentages
Age (years old)	13 years old (median) Q1 = 10; Q3 = 31	
Did you have any previous knowledge about *Drosophila suzukii*?	YES	25.5%
	NO	74.5%
Could you identify *D. suzukii* from the pictures?	a. Picture 1 (*D. melanogaster*)	14%
	b. Picture 2 (*D. suzukii*)	68%
	c. Picture 3 (*Bactrocera sp*)	6%
	d. Picture 4 (*Ceratitis sp*)	12%
How does *D. suzukii* affect the soft-skin fruit production?	a. The fly bites the harvesters	4%
	b. The fly eats the fruits	4%
	c. Females lay the eggs inside the fruit	88%
	d. Females attacks the leaves of the plants	4%
Which agroecological tools were shown in the video-game?	a. Harvest frequency	23%
	b. Cleaning fallen fruit	2%
	c. Harvest alternative fruits	-
	d. All the above option	75%

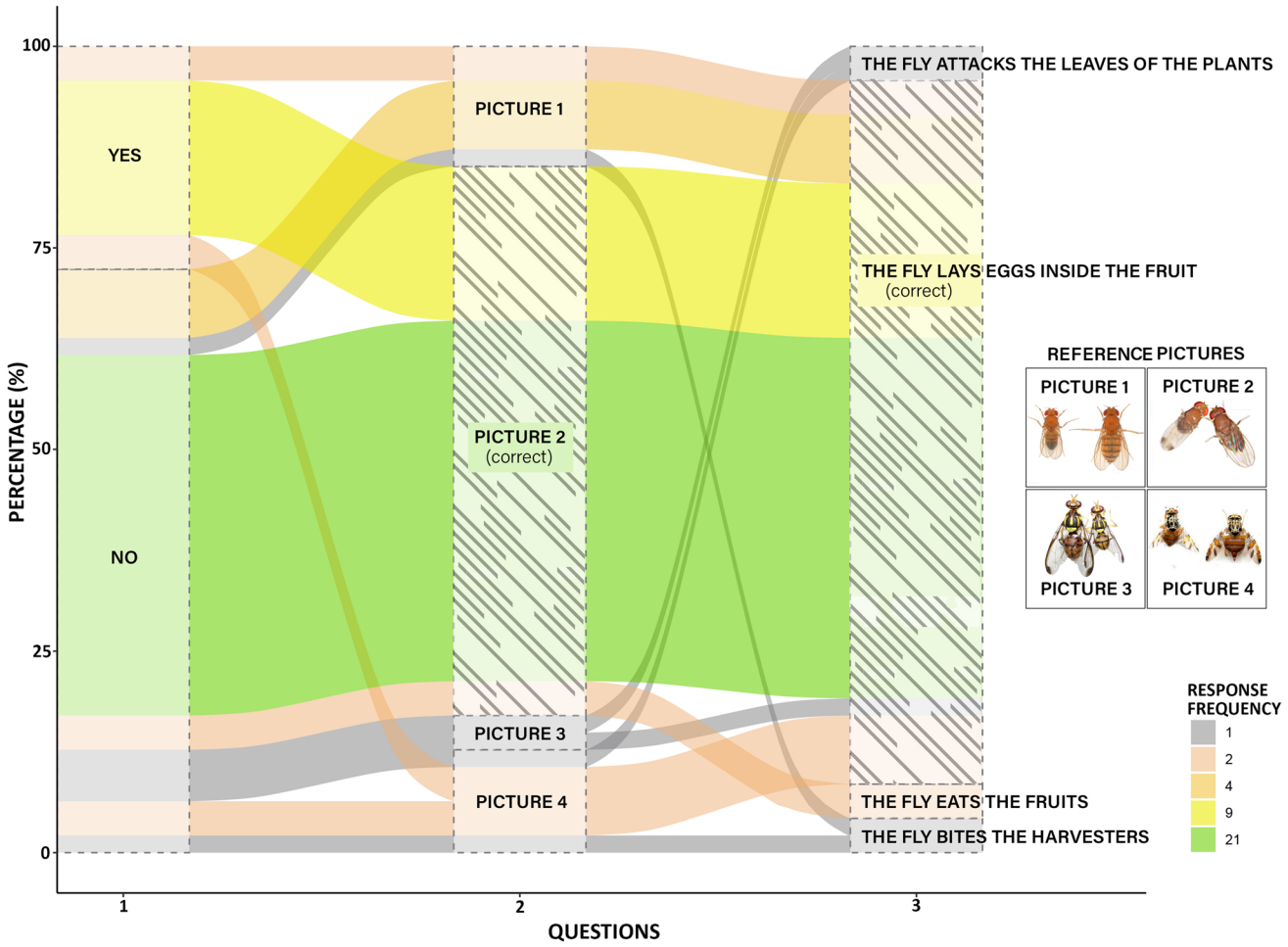

Fig. 2 Presentation of the Spotted-Stop-It video-game in a Rural Fair. Survey results shown as the percentage and frequency of the responses and the connections

of the world, changes in the farmer and the non-crop alternative hosts could be included.

Finally, different language versions could help overcome limitations of educational materials in pest management for different farmworkers (Dudley 2014). In this sense, we developed a Spanish language version called "*Te Atraparé Suzukii*," but the game can be translated to other languages as well. Also, regional public events, such as science fairs and outreach activities, could be a great opportunity to use the "Spotted-Stop-It" game, resorting to simple "arcade consoles" where the gaming community, students, and scientists could share their experience and make suggestions.

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Author contribution GD conceived and developed the project; GD and AF designed the protagonist; AF made the graphical arts; GD and JC led the writing of the manuscript. GD, AF, and LS perform the questionnaire. All authors contributed to the drafts and approved the manuscript.

Data availability Data is available from the corresponding authors on request.

Code availability Code is available from the corresponding authors on request.

Declarations

Conflict of interest The authors declare no competing interests.

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