Research Article

Received: 23 April 2020 Revised: 13 September 2020 Accepted article published: 29 September 2020 Published online in Wiley Online Library: 19 October 2020

(wileyonlinelibrary.com) DOI 10.1002/ps.6110

The economic impact of *Drosophila suzukii*: perceived costs and revenue losses of Swiss cherry, plum and grape growers

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Abstract

BACKGROUND: *Drosophila suzukii* can lead to substantial damages in horticultural production. In this article we analyze revenue losses and cost increases due to *D. suzukii* as perceived of Swiss cherry, plum and grape growers. Moreover, we investigate associations between farm and grower characteristics and revenue losses and perceived costs increases. We surveyed Swiss growers of cherries, plums and grapes repeatedly in the period 2016–2018 ($N = 1572$).

RESULTS: We find that 76% of cherry, plum and grape growers faced additional costs due to *D. suzukii*. In contrast, yield losses due to *D. suzukii* infestation were small on average, but nevertheless high for some growers. We find substantial heterogeneity in perceived costs and revenue losses across crops, years and farms. Larger farms are found to face lower perceived additional costs, suggesting scale effects in prevention and control of *D. suzukii*. Growers with a higher inter-varietal diversity perceived additional costs to be higher. Furthermore, organic farming was negatively associated with expected additional costs.

CONCLUSION: Our results suggest that the economic impact of invasive species such as *D. suzukii* goes far beyond reductions in yield quantity and quality, but rather stems from higher costs due to the need to establish preventive and control measures. Heterogeneity in costs and revenue losses suggests that policy measures to support growers need to be tailored to crops and farm types. Policies supporting improvements of measures against *D. suzukii* and other newly occurring alien pests and reduce additional costs such as more efficient preventive and control measures merit further encouragement.

Keywords: crop damage; pest management measures; invasive species; perceived costs; growers' survey

1 INTRODUCTION

The invasive insect pest *Drosophila suzukii* is a major threat to horticultural production. The pest has advanced rapidly since it spread from its south-eastern Asian native habitat to the United States and Europe in the late 2000s.[1] Unlike other *Drosophila* species, *D. suzukii* can pierce the skin of intact fruit to lay its eggs in ripening and ripe fruit.[2]

Larval feeding causes both damage within the fruit and secondary pathogen infection.[3,4] *Drosophila suzukii* attacks a wide range of hosts including berries, cherries, plums and grapes as well as many wild-growing, fruit-bearing plant species.[5,6] Infested fruit is unmarketable due to zero tolerance policies.[7] In response, growers adopt multiple measures to prevent and control infestation.[3,8,9] The economic impact of *D. suzukii* is expected to be substantial, but its magnitude is still largely unknown.[10–12]

In this article, we provide estimates of the economic impact of *D. suzukii* on Swiss cherry, plum and grape production. We surveyed growers over 3 years ($N = 1572$) to assess perceived additional costs, comprising costs arising from the implementation of preventive and control measures plus additional labor for post-harvest sorting as well as additional costs and revenue losses expected in the next year due to *D. suzukii*. In addition, we use regression analysis to investigate associations between crop, farm and grower characteristics and perceived costs increases and revenue losses. Moreover, we present detailed documentation on the measures taken by growers to prevent and control *D. suzukii*.

Previous research has often focused on potential yield losses due to *D. suzukii* (if untreated) and combined this with the total production value to estimate possible economic damage (e.g. Yeh *et al.*,[13] Bolda *et al.*,[14] De Ros *et al.*,[15,16] Benito *et al.*,[17]). Recent studies also surveyed growers to gauge effective yield losses. For example, DiGiacomo *et al.*[18] used a sample of 82 growers to estimate effective yield losses in raspberry production in Minnesota and conclude that the median incurred yield loss was 20% in 2017. The economic impact of *D. suzukii* is heightened by substantial extra costs arising from the implementation of preventive and control measures plus additional labor for

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Table 1. Overview of the number of survey participants per year and crop

Crops	2016	2017	2018	Total
Cherries	Not conducted	94	109	203
Plums	112	74	91	277
Grapes	372	331	389	1092
Total	484	499	589	1572

Note: Cherries were not conducted in 2016 due to administrative reasons of the project.

postharvest sorting.[1,20] For example, Burrack[19] presents survey results from 249 growers in the United States and 44% of respondents state they faced increased labor costs due to *D. suzukii*. Moreover, various estimates for additional costs have been provided (Goodhue *et al*.,[10] Burrack,[19] De Ros *et al*.,[15] Farnsworth *et al*.,[11] Mazzi *et al*.[12]) and cost–benefit analysis have been carried out for specific measures (e.g. Del Fava *et al*.[20]). However, there is a lack of large-scale multi-year and multi-crop studies investigating expected additional costs and revenue losses jointly. Moreover, while previous research has accounted for the temporal and spatial heterogeneity of pest pressure (e.g. De Ros *et al*.[16]), the heterogeneity of farm structures and growers' subjective perceptions and preferences have rarely been investigated (see e.g. Burrack[19]).

We add to this literature by providing insights into, and explaining the heterogeneity of, additional costs and revenue losses due to *D. suzukii*. More specifically, we focus on additional costs as perceived by growers (in the year the survey took place), expected additional costs (in the coming year) and expected revenue losses. We extend previous work and consider growers' and farm characteristics to explain heterogeneity in perceived costs and revenue losses. Farm structures (e.g. farm size and capital endowment) are expected to affect the costs for implementing measures to prevent and control *D. suzukii*. For example, larger farms may have scale effects to implement these measures. Furthermore, there are significant differences in growers' perception of costs and benefits as well as their subjective risk perception and preferences (e.g. Iyer *et al*.[21]). Therefore, individual growers' responses to *D. suzukii* are largely heterogeneous, even when they face similar pest pressure. In this article, we explore the heterogeneity underlying these impacts and report perceived additional costs, expected additional costs and expected revenue losses using data obtained from surveys conducted with Swiss growers of cherries, plums and grapes over 3 years (2016–2018).

In the remainder of this article, we first provide relevant background information on Swiss fruit production and *D. suzukii* together with a framework synthesizing possible economic impacts. Secondly, we present the methodological approach including data collection and analysis. Thirdly, we put forward our results and provide insights into infestation levels, measures taken against *D. suzukii*, perceived additional costs, expected additional costs and expected revenue losses due to *D. suzukii*.

2 BACKGROUND

We focus on *D. suzukii* impacts on fruit production, namely cherries, plums and grapes (i.e. including wine and table grapes) in Switzerland. These crops are highly susceptible to *D. suzukii* infestation and are economically significant. The total acreage under fruits in Switzerland is *ca* 6258 ha.[22] Of this area under fruits, cherries are grown on 9%, plums on 4% and table grapes on 0.29%. Grapes cultivated for wine production cover 14712 ha.[23] While the acreage under fruit production and the cultivation of grapes used for wine production is small, the value of production is high and a crucial component of Swiss agriculture. The production of fruit and grapes for wine production represented 4% and 7% of the total agricultural production value in 2018,[24,25] respectively. *Drosophila suzukii* causes significant economic damage to cherries and, to a lesser extent, to plums and grapes.[12,23,26] Currently used measures in Switzerland against *D. suzukii* are found to generate additional costs, but, when effective, can offset possible yield losses.[12]

A wide range of measures are available to growers to manage *D. suzukii*, but none of them is entirely effective on its own, nor is it necessarily cost-efficient. Here we briefly describe the most relevant measures in Swiss fruit production. Exclusion netting can reduce *D. suzukii* pest pressure in crops[27–29] with no negative effects on the quality of the grown produce.[30] In addition, nets protect crops from other pests, insects and birds.[27] However, growers face significant additional costs for the infrastructure needed. For example, Mazzi *et al*.[12] calculated that enclosure nets in Swiss cherry production would cost 200 CHF[1] per year and generate additional labor costs of 210 CHF[2] per ha and year. Note that because the additional investment in nets is substantial, these costs critically depend on lifetime of these nets.

Moreover, sanitation measures are used that involve keeping the herbaceous layer low and the correct removal and disposal of unharvested, overripe and infested fruits. They are most effective in terms of preventing reservoirs of infestation that may jeopardize later-maturing, neighboring crops.[3] Baited traps are used to detect the presence of *D. suzukii*. Surveillance measures allow control precautions to be implemented at the right time.[31] When deployed in large numbers, traps can contribute to population reduction. However, mass trapping has also been questioned in the literature, since the traps may be counterproductive if they attract flies to the crops from unmanaged surrounding habitats.[32]

Growers are advised to inspect fruit visually for signs of infestation, however, this approach is labor-intensive, e.g. Mazzi *et al*.[12] estimated the additional labor demand to be ten hours per hectare and year. Growers can circumvent higher pest pressure by harvesting early. However, they may then face revenue losses as fruit, which is harvested early, may fail to satisfy consumers' quality expectations.[33] Finally, growers may apply insecticides.[34] In the United States, conventional growers rely mostly on insecticide-based pest management[33] although a recent study suggests that the use of integrated pest management measures[3] is less costly to growers than preventive calendar-based insecticide[4] spraying.[35] In Switzerland, there are a number of regulations (including

[1]This is equivalent to 208 US dollars.

[2]This is equivalent to 218 US dollars.

[3]Different integrated pest management strategies exist. The study refers to monitoring-based insecticide applications. This involves a monitor-to-guide spray strategy, with weekly monitoring during the season and spraying when a certain threshold of *D. suzukii* is reached in the monitoring traps.[35]

[4]Calendar-based spraying strategy involves spraying throughout the whole season with a broad-spectrum of insecticides without monitoring *D. suzukii*, see Fan *et al*.,[35] Van Timmeren *et al*.[36]

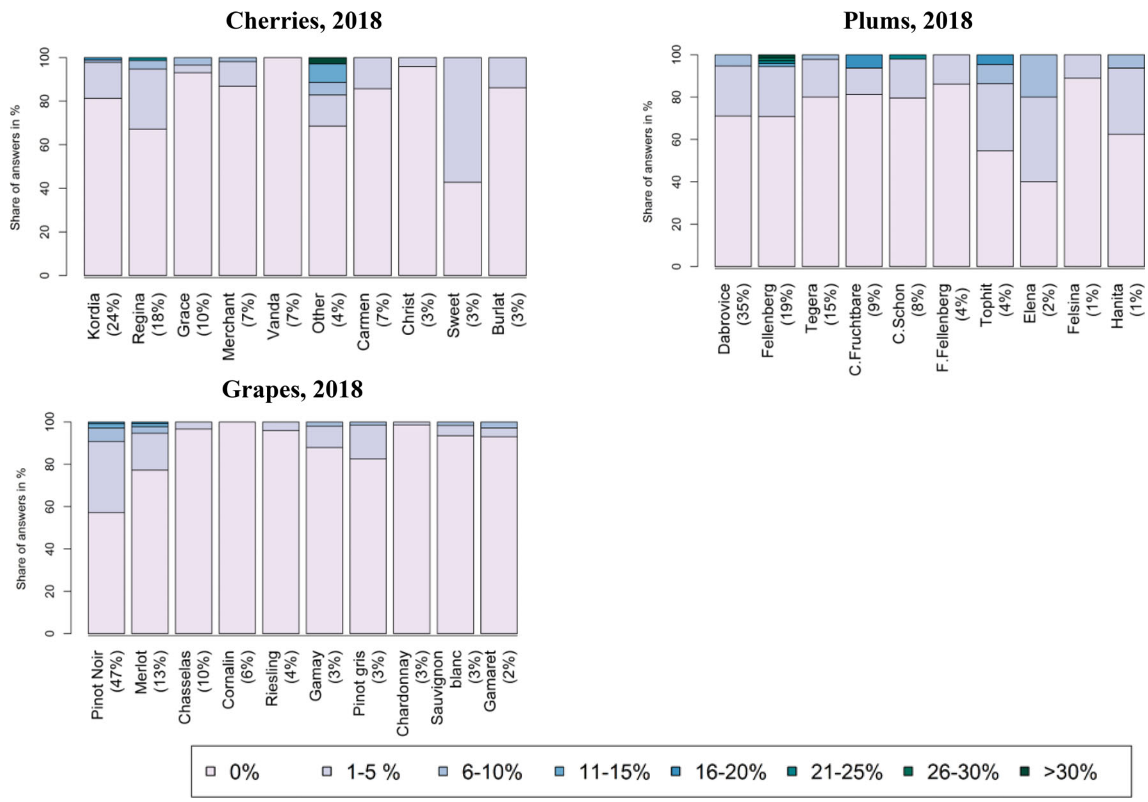

Figure 1. Infestation levels per crop per variety for the harvest 2018.

cross-compliance regulations[5]) regarding the use of insecticides. Insecticide use in Switzerland is only recommended as the last resort when other control measures fail.[12] One of the challenges growers face when using insecticides is the maintenance of an effective residue on the fruit, without exceeding the maximum residue limits or unnecessarily impairing environmental quality[6].[38]

2.1 Economic framework to assess the impact of *D. suzukii*

The economic impacts of *D. suzukii* arise from different components. Firstly, infestation may lower the quality and quantity of yields. Thus, changes in revenues may arise from decreases in yields and prices (reflecting lower quality), but may be reduced by negative yield-price correlations, the so-called natural hedge[7]. Secondly, pest management measures generate extra costs for prevention and/or pest control and both can create additional workload.

Changes in growers' profits due to the presence of *D. suzukii* can be formulated as follows:

$$\Delta\pi_i = \Delta \mathrm{Yield}_i \cdot \Delta \mathrm{Price}_i - \Delta \mathrm{Cost}_{\mathrm{Prevention}\ i} - \Delta \mathrm{Cost}_{\mathrm{Pest\ Control}\ i} - \Delta \mathrm{Cost}_{\mathrm{Labour}\ i} \tag{1}$$

Impacts of *D. suzukii* on yields and costs depend critically on farm structures and growers' perceptions[8]. The index i in Eqn (1) represents $i = 1, \ldots, N$ farms in our analysis. We hypothesize that the differences in farm structures and growers' subjective risk and cost perception lead to heterogeneous responses to *D. suzukii*. As a result, costs and damage can differ substantially despite similar pest pressure. Moreover, damage is likely to be heterogeneous over time as pest pressure is, at least to some extent, stochastic, i.e. determined by uncontrollable elements, such as local weather and experience gained over time.

3 DATA AND METHODS

3.1 Survey and data

In 2016, 2017 and 2018[9], we used an online questionnaire to survey Swiss growers of cherries, plums and grapes (see Table A1 in Appendix). The survey was developed together with experts in the field of fruit production, extension specialists and growers. It was then pre-tested with growers. We sent out the surveys via a link provided to the growers by email in collaboration with a number of Swiss cantonal agricultural services. The link was also sent out on periodic information leaflets issued by the Swiss Center of excellence for agricultural research (Agroscope). As a result of

[5]Cross compliance regulations comprise conditions that growers must fulfil to qualify for direct payments (for an overview, see FOAG,[34] Huber *et al.*[37]).

[6]Note that in Switzerland, kaolin, a naturally occurring mineral clay, is widely used, especially in vineyards.[8] Kaolin has a repellent effect and dissuades oviposition, while posing no significant hazards to human health. Kaolin can be comparably effective as other insecticides as it inhibits oviposition and is a viable option especially for production systems that are difficult to protect with nets.[39]

[7]Large shocks in production might induce higher market prices and thus partially compensate for the yield losses, see Finger.[41] We focus on revenue changes here so that this natural hedge is implicitly controlled for.

[8]For example, Mazzi *et al.*[12] provide an overview of different costs of pest management measures against the *D. suzukii* in the context of Switzerland.

[9]These surveys extended previous efforts in collecting relevant information on *D. suzukii* in Switzerland (see e.g. Mazzi *et al.*[12]).

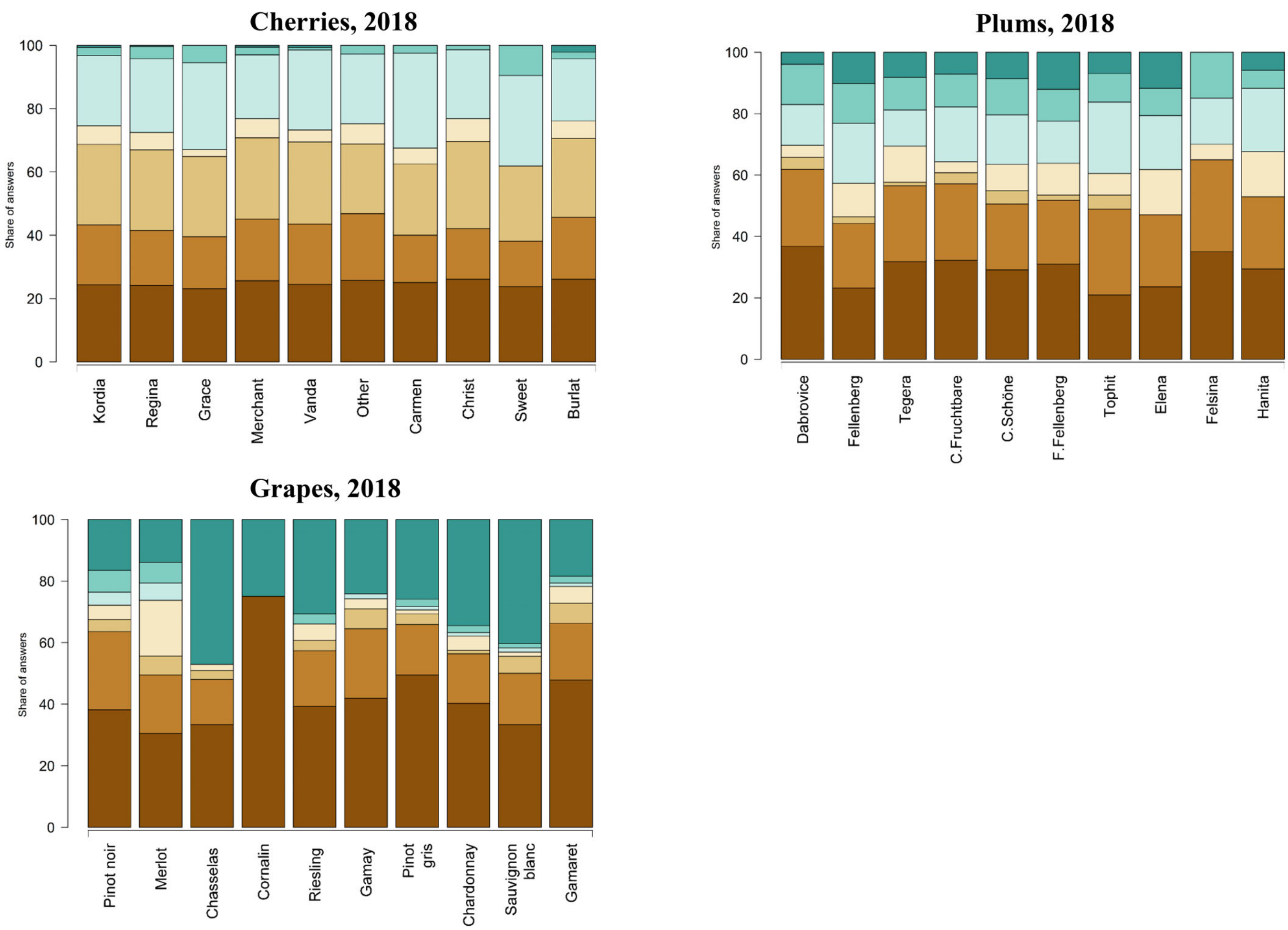

Figure 2. Measures taken against *Drosophila suzukii* per variety for the harvest 2018.

this sampling strategy, the response rate is unknown. However, the number of here included cherry and plum growers represent approximately 10% of the total Swiss fruit growers[10] and the grape growers represent about 21% of total Swiss grape growers[11]. The grower and farm characteristics of the samples in our survey are overall in line with the average Swiss farm and grower characteristics[12]. Our survey was conducted in the three main official languages of Switzerland (i.e. German, French and Italian) and covers the main regions of cherry, plum and grape production, although for some crops, according to experts, a couple of key cantons were underrepresented[13].

The surveys went out following the crop harvest and remained online for 1 month. Grape growers are overrepresented in our sample as 70% of the participants in our sample are grape growers. A total of 9% of the surveyed growers produce according to the guidelines of organic farming associations.

Table 1 shows the sample sizes for each year and crop.

The surveys, datasets and the codebooks describing the variables are publicly available online on the ETH Zurich Research Collection: http://hdl.handle.net/20.500.11850/292794.

We collected data on perceived infestation levels as well as harvest losses and measures taken specifically to control *D. suzukii*. Growers could also declare whether the harvest was aborted because of infestation (1 = aborted harvest, 0 = harvest not aborted). Moreover, we asked growers to indicate perceived additional costs (in percent per kilogram yield arising from the measures taken against *D. suzukii*) in the year of the survey as well as additional costs expected for the next year and revenue losses

[10]Grape growers producing grapes for wine as an end-product are not included as they are considered separately in Swiss statistics (see FOAG, Landwirtschaft und Ernährung 2018[40]).

[11]Personal communication from FOAG: In Switzerland, there are 4981 grape growers (without differentiating between table and wine grape growers and does not include hobby grape growers).

[12]Female growers represent in all 3 years around 6% of the participants, which is also the percent of female farmers in Switzerland (6%). In Switzerland, more than half of the farmers are 50 years old and above and in our sample, the average age is 50 years old. The average farm size is of 16 ha, which is above average. This is explained by the participation of a number of cooperatives, which reported larger surfaces. Organic growers represent between 8% and 11% of farms in the samples, this is a bit below the percentage of organic farmers in Switzerland (12%) (see FOAG, Landwirtschaft und Ernährung 2018[40]).

[13]In the case of grape production (2016) some cantons are underrepresented (i.e. Zurich, Schaffhausen, Thurgau). One of the reasons for this underrepresentation is that some cantonal services did not forward the survey.

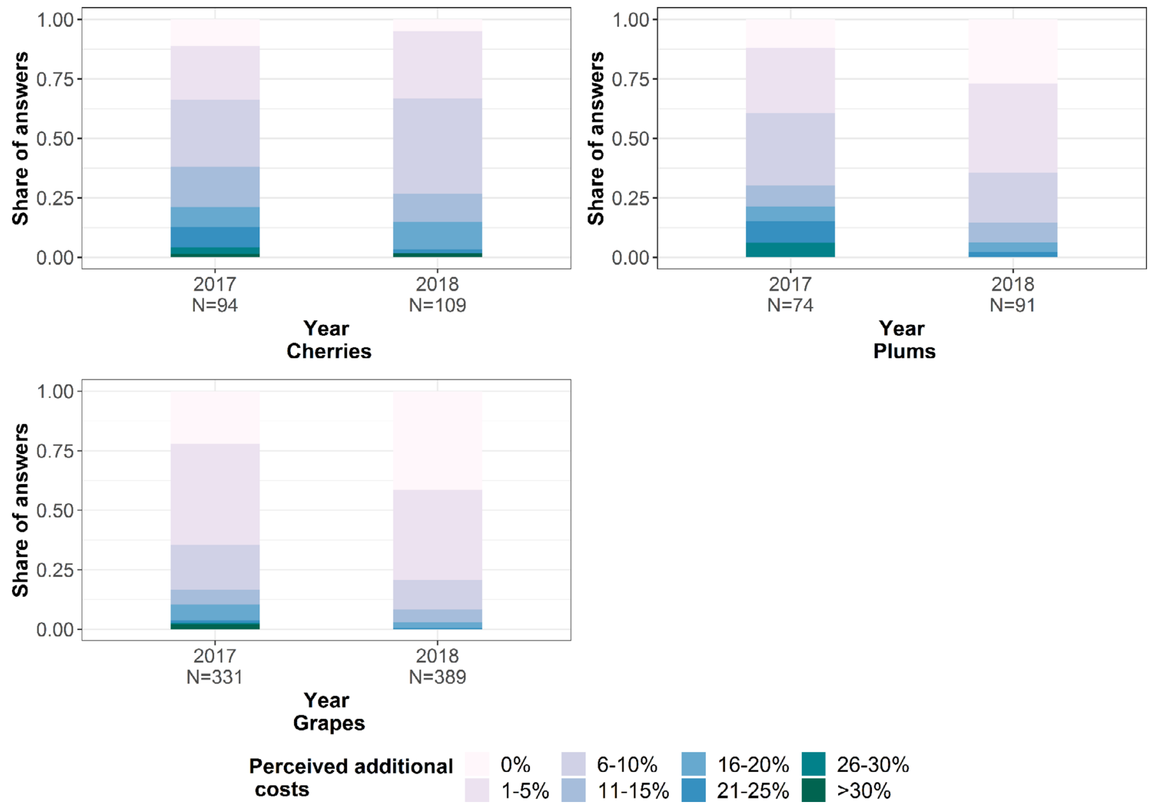

Figure 3. Perceived additional costs due to *Drosophila suzukii* per crop (year 2017–2018).

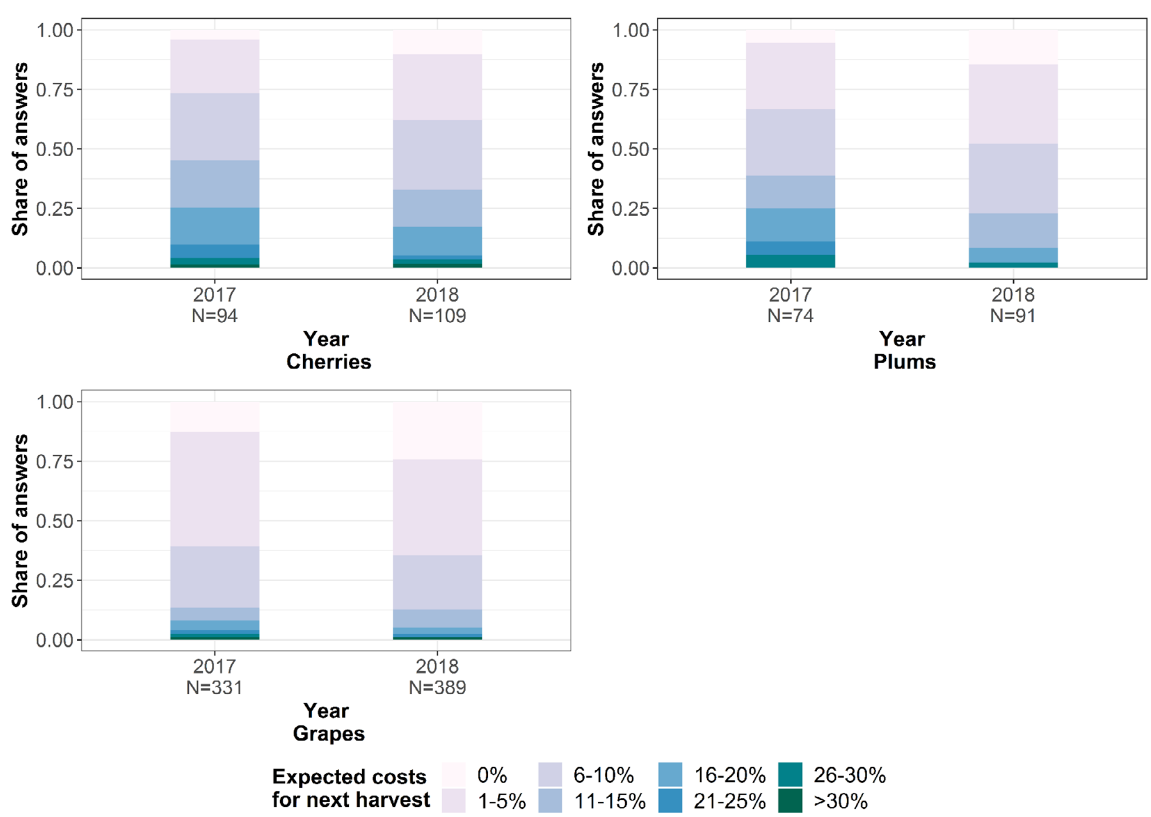

Figure 4. Expected additional costs due to *Drosophila suzukii* per crop.

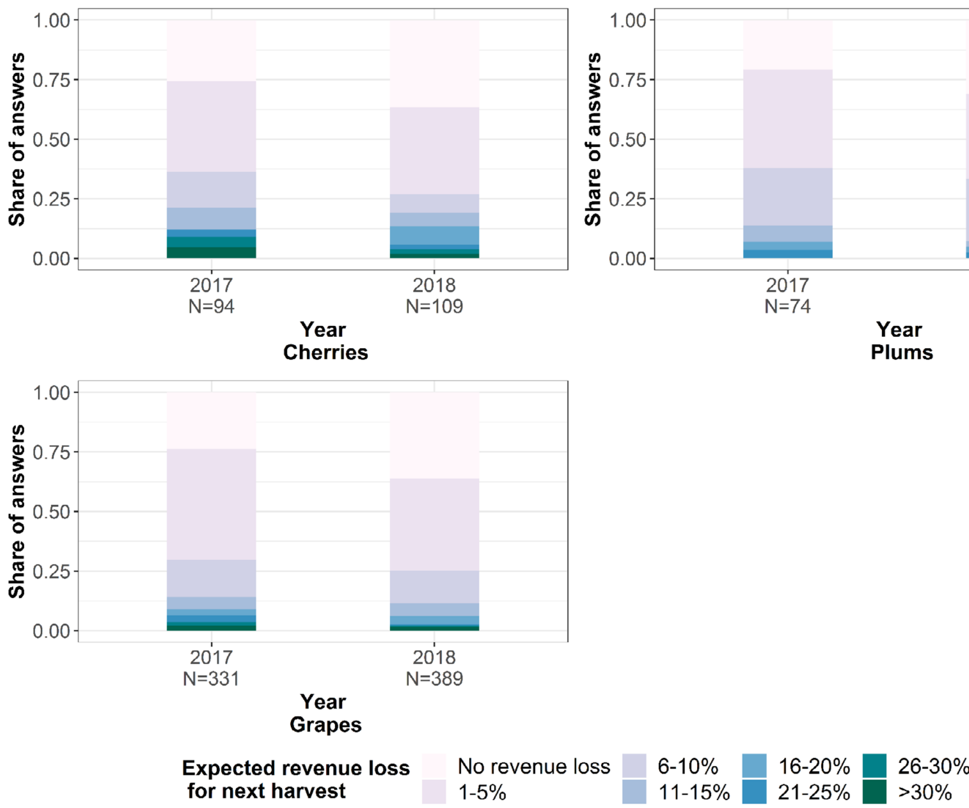

Figure 5. Expected revenue loss due to *Drosophila suzukii* per crop for 2017 and 2018.

expected in the next year due to *D. suzukii* (see Appendix Table A1 for an overview of the relevant questions).

The perceived infestation levels of the crops were surveyed at the variety level with a percentage scale on the level of infestation, i.e. the subjective evaluation of the growers. A total of 63 different varieties were considered (20 for cherries, 13 for plums and 30 for grapes). Based on expert interviews, we defined infestation levels between 'no infestation' to over 75% infestation (see Appendix Table A1). These infestation levels were surveyed per crop per variety, more specifically for each variety for which the grower could state the level of infestation. An overview of infestation levels per crop was obtained by merging the data available on the surface area per variety and whether the grower viewed this variety as infested or not and then calculating the overall share of infested area per crop.

For every variety, we asked which measures were taken specifically to prevent or control *D. suzukii*. Measures included in the survey were the use of sanitation measures, control for infestation (i.e. visual inspection, control for infestation by the cantonal advisory services, trap control or salt control), the use of nets, mass-trapping, harvesting the crop early and the use of insecticides. Growers could choose multiple options, and specify measures taken.

The survey included a wide range of growers' characteristics such as age and gender. Moreover, growers' risk aversion was assessed via a series of questions based on a 11 Likert scale (see Iyer *et al.*[21]). Questions on attitude towards risk were asked, namely in the domains of production, market and prices, external financing and agriculture in general (see Appendix Table A1). The farm characteristics surveyed included whether the production system follows organic standards, the farm size (in hectares), specialization of the farm, share of off-farm income, the share of land leased by the growers and the surface cultivated with fruit per variety (see Appendix Table A2 for a detailed description of variables). The Shannon Index[14] was calculated based on the number of varieties and the surface allocated to each variety. The higher the Shannon Index, the greater the inter-varietal diversity.

Based on the farms' location, we combined survey data with other data sources and added farm-specific information on meteorological variables, i.e. average precipitation, average temperature (see Appendix Table A2 for an overview) and distance to the closest larger agglomeration[15]. See Table A3 for summary statistics.

3.2 Statistical analysis

In a first step, we estimated infestation levels and summarized measures taken against *D. suzukii* per crop and per variety. We considered the ten most common varieties (based on the cultivated surface). For each crop, we focused on (i) the perceived additional costs in the year surveyed, (ii) the additional costs expected in the following year and (iii) the revenue losses expected in the following year.

In a second step, we identified the growers' and farm characteristics associated with disproportionately high perceived additional costs,

[14]To calculate the Shannon Diversity Index, we took the surface of parcel i planted with variety j divided by the total surface of the parcel i multiplied by the log surface share (α_{ji}). See formula: $-\sum \alpha_{ji}/\alpha_i * \ln\alpha_{ji}/\alpha_i$. For more details, see Smale[42]).

[15]Agglomeration is defined as >10 000 inhabitants. The distance is measured in travel time using information derived from Google maps and using the R Package 'gmapsdistance', see: https://cran.r-project.org/web/packages/gmapsdistance/gmapsdistance.pdf

Table 2. Factors associated with perceived additional costs, expected additional costs and expected revenue losses

	(1) Perceived additional costs OLS	(2) Expected additional costs OLS	(3) Expected revenue losses OLS
Age	−0.05** (0.02)	−0.03** (0.01)	−0.07*** (0.02)
Gender (male)	0.17** (0.05)	−0.005 (0.05)	0.07 (0.07)
Risk aversion	−0.002 (0.01)	0.00 (0.01)	−0.02 (0.01)
Farm size	−0.84*** (0.29)	0.05 (0.36)	0.53 (0.56)
Diversification (Shannon Index)	0.07** (0.02)	0.04*** (0.01)	−0.01 (0.02)
Share of off-farm income	−0.04 (0.03)	−0.006 (0.03)	0.01 (0.04)
Land tenure	0.02 (0.03)	0.01 (0.02)	0.04 (0.04)
Organic farming	0.00 (0.04)	−0.11*** (0.04)	−0.04 (0.05)
Focus specialized	−0.05 (0.04)	−0.22 (0.03)	−0.01 (0.05)
Plums	−0.02 (0.05)	−0.07** (0.03)	0.11* (0.06)
Grapes	0.01 (0.05)	0.03 (0.04)	0.15** (0.07)
Year 2017	0.00 (0.03)	0.00 (0.03)	0.07* (0.04)
Year 2018	−0.13*** (0.03)	−0.07** (0.02)	−0.04 (0.04)
Control variables	Distance to town, Precipitation squared, Precipitation, Temperature, Temperature squared, Swiss language regions (French, German, Italian)		
Adjusted R^2	0.100	0.061	0.031
F Value	5.09	3.79	1.73
P Value	0.00	0.00	0.05
Number of observations	735	703	639
Mean variance inflation factor	1.25	1.28	1.30

Note: *,** and *** denote significance at the 10%, 5% and 1% level, respectively. Standard errors are in parenthesis. Perceived additional costs are the perceived additional costs estimated in percent per kilogram yield arising from the measures taken against *Drosophila suzukii*. The first column represents an ordinary least square (OLS) with perceived additional costs as the dependent variable (1/0), 0 = no additional costs, 1 = additional costs. The second column represents an OLS with expected additional costs as the dependent variable (1/0), 0 = no expected additional costs, 1 = expected additional costs. The third column shows an OLS with expected revenue losses as the dependent variable (1/0), 0 = no expected revenue losses, 1 = expected revenue losses. Variance inflation factor is calculated without the squared variables for temperature and precipitation, the crop, year and language region. The sample used here is a subset of the sample with 1170 fruit growers. The sample size varies as some values are missing since not all respondents answered all questions. The adjusted R^2 values are low, however this is expected because we do not have all the data to include all the relevant predictors. The *P*-values for the *F* test indicate that the regression model fits the data better than the model with no independent variables.

expected additional costs and expected revenue losses. To this end, we performed a regression analysis considering the three dependent variables, perceived additional costs, expected additional costs and expected revenue losses, as binary variables (i.e. either zero or larger than zero). We estimated the variation of the following equations:

$$\text{Perceived.add.costs}_i = \beta_0 + \beta_1 \text{Farm charact.}_i + \beta_2 \text{Grower charact.}_i + \beta_3 X_i + \theta + \varepsilon_i \tag{2}$$

$$\text{Expected.add.costs}_i = \beta_0 + \beta_1 \text{Farm charact.}_i + \beta_2 \text{Grower charact.}_i + \beta_3 X_i + \theta + \varepsilon_i \tag{3}$$

$$\text{Expected.rev.losses}_i = \beta_0 + \beta_1 \text{Farm charact.}_i + \beta_2 \text{Grower charact.}_i + \beta_3 X_i + \theta + \varepsilon_i \tag{4}$$

Perceived. add. costs$_i$ reflects whether the grower stated she or he had additional costs (> 0%), i.e. we transformed the dependent variables into binary variables (1 = perceived additional costs, 0 = no perceived additional costs). Farm charact.$_i$ covers farm characteristics such as farm size, inter-varietal diversity on the farm (i.e. Shannon Index), share of off-farm income, land tenure, production system and specialization of the farm. Grower charact.$_i$ are grower characteristics and includes age, gender and risk aversion. We account for several control variables. X_i represents meteorological variables and distance to the closest larger agglomeration. The θ includes dummy variables for the year in which the survey took place, the crop (i.e. cherries, plums or grapes) and the region of Switzerland (i.e. French, German or Italian-speaking) and ε_i is an error term. We performed the same regression with expected additional costs and expected revenue losses as dependent variables as presented in Eqns (3) and (4).

For our main analysis, we estimated Eqns (2)–(4) using ordinary least squares (OLS) regression. We also used probit estimation and the interpretation of coefficient estimates does not change to the here presented[16]. Further robustness checks also include more restricted OLS specifications with fewer variables. Moreover, we used ordered probit regression. This is especially useful to recover information lost by creating binary variables from the categorical data (see Appendix Table A1 for the data and categories). The dependent variable for the ordered probit regression comprised

[16]The analysis of binary dependent variables may appear to call for non-linear models such as the probit, but OLS is an option (see Angrist[43]). Coefficients of the OLS and the marginal effects generated by probit are likely to be indistinguishable. We chose OLS because the coefficients are simpler to interpret, however the probit is available in the Appendix (Tables A10 and A11) and interpretation of results remains unaffected.

three categories. The first category represented 0% perceived additional costs, expected additional costs or expected revenue losses, the second category 1–20% perceived additional costs, expected additional costs or expected revenue losses, and the third category > 20% perceived additional costs, expected additional costs or expected revenue losses. The intervals chosen in the survey for perceived additional costs, expected additional costs and expected revenue losses were based on expert interviews (see Appendix Table A1 with intervals). For the purpose of the analysis, we merged intervals[17] into three intervals, in order to have three equivalent categories for every year where the survey was undertaken. Our results are insensitive to the chosen estimation strategy and model specification.

Note that while for the descriptive analysis, we used the entire sample and all responses, we used a cross-sectional dataset for the regression analysis. This cross-sectional dataset is constructed using all first observations per farm within the survey period 2016–2018[18]. For example, if the grower participated in the survey for all 3 years, we used the data from 2016. Thus, the sample used for the regression analysis is reduced from the initial 1572 growers to 1130 participants.

Finally, we calculated the variance inflation factor for the OLS regressions to test for multicollinearity between variables chosen. Moreover, a correlation matrix for the dependent variables, i.e. perceived additional costs, expected additional costs and expected revenue losses, is presented to reveal how these variables are associated.

4 RESULTS

4.1 Infestation levels

An overview of perceived infestation levels per year per crop is provided in Figs A1 and A2 and Tables A4–A6 in the Appendix. These levels represent *D. suzukii* infestation as perceived by growers in terms of the share of infested surface on their land. The share of perceived infested surface for cherries and plums was lowest in 2018 when infestation was reported at under 15% of the cultivated surface in our sample (see Appendix Tables A4–A6 for an overview of percentage of cultivated surface infested). The lowest share of infested surface for grapes occurred in 2017 when 10% of the cultivated surface was affected. Overall, our results indicate that for cherries, plums and grapes, under 30% of the cultivated surface was infested in the 3 years considered.

Figure 1 provides a detailed overview of growers' perceived infestation levels by considering the varieties for each crop. Due to the numerous varieties surveyed (20 for cherries, 13 for plums and 30 for grapes), we restrict presentation to the top ten in terms of cultivated surface. As shown in Fig. 1, growers consider some varieties to be more prone to infestation than others. For instance, 40% of those cherry growers cultivating the 'Sweet' variety regarded it to be prone to infestation and 40% of the plum growers cultivating the 'Elena' variety considered it to be vulnerable. This also applies to grape varieties, where for instance 40% of the grape growers cultivating the variety 'Pinot noir' declared this variety as infested. In our survey, around 2% of growers in our sample (including the three crops, cherries, plums and grapes) declared that they aborted the harvest (see Appendix Table A7).

4.2 Management measures implemented against *D. suzukii*

The use of management measures is relatively similar and stable across the years (for an overview of measures taken per year per crop, see Fig. A3 in the Appendix). The application of insecticides and early harvesting are more widely adopted in the case of cherries and plums than in the production of grapes (see Table A8). The overview by variety provides insights into the heterogeneity of the measures adopted (Fig. 2). For instance, sanitation measures alone suffice for the variety 'Cornalin', while a number of grape growers also use fine-meshed nets for the variety 'Merlot'.

4.3 Expected additional costs due to *D. suzukii*

Figures 3 and 4 provide an overview of the perceived additional costs due to *D. suzukii* in the year the survey took place and expected additional costs due to *D. suzukii* per year[19] for the next harvest. These estimates are expressed in percent per kilogram yield. Perceived additional costs faced by growers in the year of survey are presented in Fig. 3 (see Appendix Fig. A5 for the year 2016). Perceived additional costs faced by growers are lowest in 2018, except for cherry growers. As shown in Fig. 4, the number of growers expecting additional costs for the next harvest is lower in 2018 than in 2017.

4.4 Expected revenue losses for the next harvest due to *D. suzukii*

Figure 5 provides an overview of expected revenue losses due to *D. suzukii* for the next harvest: 72% of cherry growers, 77% of plum growers and 73% of grape growers expected revenue losses due to *D. suzukii* in 2017. In 2018, these shares are lower, i.e. 60% of cherry growers, 67% of plum growers and 61% of grape growers expect revenue losses for the next year. Most of the growers estimate these losses to be between 1 and 5% of their revenue. However, a small percentage of cherry and grape growers anticipate revenue losses of over 30%. This illustrates the heterogeneity of growers' perception of the threat from *D. suzukii*.

The scales used for the results concerning expected revenue losses in the 2016 survey differ from those used in 2017 and 2018 (see Appendix Fig. A6 for 2016 results).

4.5 Perceived additional costs, expected additional costs and expected revenue losses: associations with farm and grower characteristics

In Table 2 we present the results of the regression analysis undertaken using (i) perceived additional costs (column one), (ii) expected additional costs (column two) and (iii) expected revenue losses (column three) as dependent variables. See Appendix Tables A10 and A11 for coefficients of the control variables and Table A12 for sensitivity tests. Variance inflation factors are all below the value two, indicating the absence of multicollinearity (Table 2, see Appendix Table A13 for all values of variance inflation

[17]For 2016, we had six intervals, and for 2017 and 2018 we have eight intervals, see Appendix Table A1.

[18]We did not use the panel data because the sample size for panel data with farms that participated in all years is small ($N = 61$ fruit growers). Additionally, we did not observe large variations of measures taken by fruit growers over years (e.g. a net is installed several years) so that costs are likely not changing massively over time. Moreover, several of the explanatory variables considered are time-invariant. As a result, the use of panel estimation techniques did not lead to meaningful results, yet are available upon request.

[19]The scales used for 2016 were different. Therefore these results are presented in the Appendix Fig. A4.

factors). We find that perceived additional costs and expected additional costs are positively correlated (correlation coefficient of 0.5, see Appendix, Table A9), i.e. higher perception of additional costs in the present implies a tendency to expect higher additional costs in the future. Consequently, expected additional costs and expected revenue losses are strongly associated (correlation coefficient of 0.4).

We find that growers' age is associated negatively with perceived additional costs, expected additional costs and expected revenue losses. The variable gender (male) is positively related with perceived additional costs. In our case study, plum and grape growers are associated with higher expected revenue losses than cherry growers. Further growers' characteristics included are not statistically significant.

Growers managing larger farms are associated with lower perceived additional costs. Farm diversification, i.e. the Shannon Index, is positively associated with perceived additional costs and expected additional costs, indicating that growing more varieties on a farm is linked to higher perceived and expected additional costs. Organic growers are found to expect lower additional costs in the next period than conventional growers. Furthermore, in 2018, perceived additional costs and expected additional costs are significantly lower than in 2016. In addition, we find that expected revenue losses were higher in 2017.

Results of the probit regression and the ordered probit regression are available in the Appendix (Tables A10 and A11). In general, results lead to similar conclusions as the OLS regression presented earlier.

5 DISCUSSION

We performed a survey on the economic impact of the occurrence of the insect pest *D. suzukii* involving 1572 Swiss cherry, plum and grape growers over a three-year period (2016–2018). The perceived infestation is found to be highly dependent on year, crop and specific variety. For instance, cherry and plum growers perceived infestation levels to be higher in 2017, while grape growers considered infestation levels to be highest in 2018. For grapes, the *D. suzukii* infestation varies much more across varieties than for the cherries and plums. For instance, white grape varieties are less affected than red varieties because they are less attractive to *D. suzukii*.[44] Note that exploring differences in perceived infestation across time and space may require additional research efforts both with respect to dynamics of *D. suzukii* development and farmer perception.

Although the majority of cherry, plum and grape growers in our sample did not suffer *D. suzukii* infestation of their crops, many growers, i.e. 76% of those in our sample, declared they faced additional costs. The additional costs faced by the growers is probably due to the measures they took against the pest.

Uncertainty regarding pest pressure and/or efficacy of pest management measures may lead growers to adopt different strategies.[45] For instance, one grower may feel that there is little risk of economic damage due to pest infestation, while another grower may believe that control measures *D. suzukii* are required. This can have impacts beyond the individual farm. For example, uncertainty may encourage an excessive use of pesticides, causing negative externalities for the environment or human health.[46,47]

In our sample, sanitation measures are the most widespread control approach, with more than half of the growers reporting their use. Drivers behind growers' choice on the type of measures taken against *D. suzukii* are associated with a number of variables including farm and grower characteristics as well as the crop, the varieties and in which region they are located. Identifying the drivers behind the type of measures taken goes beyond the scope of this article. However, it must be noted that growers adopt bundles of measures, i.e. typically use a number of different measures to deal with *D. suzukii*.[8]

There is no evidence from our analysis that risk aversion has a significant effect on the expected costs and revenue losses. Previous literature shows that risk aversion could have ambiguous effects on optimal prevention efforts. While risk reduction through prevention is *per se* preferred by risk averse decision makers, it may also partly dis-incentivize investment in preventive measures (see e.g. Dionne *et al.*[48]). Although prevention reduces risks of pest occurrence, the benefits of prevention itself are uncertain (i.e. depend on the occurrence of the pest). Thus, risk aversion may not necessarily determine the extent of preventive efforts and consequently the impact of *D. suzukii* on costs and revenues.

Overall, the share of off-farm income is associated negatively with perceived additional costs and expected additional costs, but is not statistically significant. This suggests that growers with additional off-farm income pursue more risky practices on the farm because they are less dependent on the on-farm income or fewer resources such as labor to allocate at the farm (e.g. El Benni *et al.*[49]) and these growers may adopt fewer measures against *D. suzukii*, which causes lower costs.

In addition, our results indicate that perceived additional costs and expected revenue losses are not evenly distributed across farms. We find that older, and thus possibly more experienced growers, perceive lower additional costs, expect lower additional costs and lower revenue losses. Older growers may be more experienced in dealing with pests and other agronomical relevant issues in general and thus perceive lower additional costs as well as having greater self-confidence in their ability to control pest pressure. Möhring *et al*[50] find that age indeed is associated with pest management choices. In addition, we find that larger farms are associated negatively with perceived additional costs, suggesting scale effects in the prevention and control of *D. suzukii*. Moreover, growers with a higher inter-varietal diversity on their farms are associated with higher perceived additional costs and higher expected additional costs. While diversity might reduce risk exposure, high diversity can generate higher costs (e.g. Hirsch *et al.*[51]). For example, different varieties might require specific strategies, which limits the cost-efficiency potential of the individual measures. Thus, high varietal diversity does not necessarily promote the exploitation of scale effects.

Organic farming is negatively associated with expected additional costs and expected revenue losses. A number of studies show that more preventive practices are used in organic farming, thus reducing the incidence of specific pests. However, this most likely depends on the pest species and cultivation method.[52] Farnsworth *et al.*[11] find that in the United States, organic raspberry growers face higher outlays than conventional growers when dealing with *D. suzukii* due to the costly, labor intensive management practices and the high price of insecticides approved for organic use. In addition, organic growers suffer larger yield losses because the insecticides approved for organic use are often less effective.[5,11] Organic growers in our sample might have already implemented a large number of preventive measures (e.g. protective enclosures) before the appearance of *D. suzukii* and thus may face higher total costs but lower additional costs.

6 CONCLUSION

We present an analysis of costs and revenue losses due to *D. suzukii* as perceived of Swiss cherry, plum and grape growers. More specifically, we assess perceived additional costs, expected additional costs and expected revenue losses using a survey over the period 2016–2018 and also investigate determinants of heterogeneous perception of additional costs, expected costs and expected revenue losses. Our results show large economic significance of *D. suzukii* for Swiss fruit production. We find that the vast majority of growers faces additional costs due to *D. suzukii*. In contrast, yield losses due to *D. suzukii* infestation were small on average, but nevertheless high for some growers. As usual in the case of emerging pests and diseases, we expect revenue losses to decline over time, as experience in dealing with *D. suzukii* grows. Our findings suggest that perceived additional costs and expected revenue losses are largely heterogeneous, i.e. differ across years, crops and farms. Farm and grower characteristics can explain this heterogeneity partly. For example, we find larger farms perceive lower additional costs, suggesting scale effects in the prevention and control of *D. suzukii*.

Policies must consider this heterogeneity and tailor support to growers appropriately. For example, large growers may require less support to cope with higher costs. Furthermore, appropriate measures to cope with *D. suzukii* may differ. In addition, policies supporting research to improve measures against *D. suzukii* and reduce additional costs faced by growers should be further encouraged.

Future research should further explore the relationship between objective and perceived infestation levels as well as efficacy of *D. suzukii* prevention and control measures if applied in the field. Future research shall also further explore growers' rational behind different prevention and control choice in response to invasive species. Moreover, future research should address the development of improved control measures that increase the efficiency to control pest damage while at the same time reduce possible impacts for the environment and human health. This development of better strategies to cope with pests is especially important in the context of the ongoing climate warming and the expected associated increase in pressure from established and emerging insect pests.

ACKNOWLEDGEMENTS

This research was funded by the Swiss Federal Office for Agriculture (FOAG) through the R&D Task Force *Drosophila suzukii*. The authors thank the fruit growers that participated to the survey, MeteoSwiss for the data provided on weather variables and the authors thank the reviewers for constructive comments on an earlier draft of this article.

APPENDIX

Table A1 provides an overview of the main questions addressed in this article. The table shows the topic, the question included in the survey and the type of scale used for the question.

Table A1. Overview of questions of interest in survey with growers (2016–2018)

Topic	Questions	Scale
Perceived infestation levels	What was the infested percentage per variety at the harvest?[a]	0%
		1–5%
		6–10%
		11–15%
		16–20%
		21–25%
		26–30%
		>30%
Measures taken against *Drosophila suzukii*	What measures did you use against the *D. suzukii*?	1/0
	• Sanitation measures	
	• Use of fine meshed nets	
	• Mass trapping	
	• Early harvest	
	• Use of insecticides	
Perceived additional costs due to *D. suzukii*	How high do you estimate the additional costs in percent per kilogram yield that arose from the measures against the *D. suzukii*?[a]	0%
		1–5%
		6–10%
		11–15%
		16–20%
		21–25%
		26–30%
		>30%
Expected additional costs for next harvest due to *D. suzukii*	How high are the additional costs in percent expected in the coming year for the different measures you will take against the spotted-wing drosophila?	0%
		1–5%
		6–10%
		11–15%

Table A1. Continued

Topic	Questions	Scale
		16–20%
		21–25%
		26–30%
		>30%
Expected revenue loss for next harvest due to *D. suzukii*	How high is your expected revenue loss caused by the *D. suzukii* for the next harvest (in percent)?	0%
		1–5%
		6–10%
		11–15%
		16–20%
		21–25%
		26–30%
		>30%
Risk preferences	Are you willing to take risks or do you try to mitigate risks in the agricultural sector?	From 0 to 10
		0 = most willing to take risks
	Are you willing to take risks or do you try to mitigate risks in the production sectors?	10 = least willing to take risks
	Are you willing to take risks or do you try to mitigate risks in the market and prices sectors?	
	Are you willing to take risks or do you try to mitigate risks in the external financing sector?	

[a] The scale was different for grapes with: 0%, up to 5%, between 5% and 12.5%, 12.5% and 25%, 25% and 50%, 50% and 75%, > 75%. This question was asked for each variety the fruit grower had on his land. We used a larger scale in 2016, with intervals of 0%,1–19%,20–39%,40–59%,60–79%,>80%.

Table A2 provides an overview and description of the farm and grower characteristics.

Table A2. Description of variable on farm and grower characteristics

Variables	Description
Age	Age of grower
Gender (male)	Describes gender of grower
Risk aversion	Mean of growers' risk aversion over four domains: agriculture, production, market and price, external financing Likert scale: 0 = not willing to take a risk 10 = very willing to take a risk. We interchanged the values from 0 (risk loving) to 10 (risk averse)
Farm size	Total farmland in hectares
Shannon Index	Shannon Diversity Index for varieties represents the evenness and diversity of the varieties the grower has. We use the surface for each variety and calculate a Shannon Diversity Index for each grower (0 = low diversity)
Share of off-farm income	Share of off-farm income is 1 if less than 50% of earnings originates from farm and 0 if more than 50% originates from farm
Land tenure	Percentage of land leased by the grower (0 if ≤50%, 1 if >50%)
Organic farming	Production system is organic or not (1 = yes, 0 = no)
Focus specialized	Focus specialized category means that the farm is specialized in the given crop production (i.e. cherries, plums or grapes) (1 = yes, 0 = no)
Distance to town	Distance measured in seconds from the grower's location to the next town/center (>10 000 inhabitants) calculated with google maps.
Precipitation	Mean precipitation is the average rainfall over the years 1961–2016 for the municipality Long-term rainfall (yearly sum) is derived as average over the time period 1961 to 2016 from high resolution grid models that are specifically suited to capture the heterogeneous Swiss surface texture and microclimates (source: Meteo Swiss)
Temperature	Mean temperature is the average temperature over the years 1961–2016 for the municipality Long-term temperature (daily average) is derived as average over the time period 1961–2016 from high resolution grid models that are specifically suited to capture the heterogeneous Swiss surface texture and microclimates (source: Meteo Swiss)
Year 2017	Year the survey took place
Year 2018	Year the survey took place
Plums	Crop cultivated

Table A2. Continued	
Variables	Description
Grapes	Crop cultivated
French speaking region	Survey was filled out in French
Italian speaking region	Survey was filled out in Italian

Table A3 provides summary statistics for these variables.

Table A3. Results: summary statistics farm characteristics and regression, $N = 1130$

Variable of interest	Mean	Standard deviation	Missing	Complete
Perceived additional costs (1/0)	0.76	0.43	83	1047
Expected additional costs (1/0)	0.82	0.34	141	989
Expected revenue loss (1/0)	0.69	0.46	233	897
Age	52	13	42	1088
Gender (male) (1/0)	0.92	0.26	39	1091
Risk aversion (1–10)	3.99	2.26	43	1087
Farm size (ha)	26.06	456.9	51	1079
Shannon Index (0–3.5)	0.94	0.77	0	1130
Share of off-farm income (1/0)	0.16	0.36	201	929
Land tenure (1/0)	0.29	0.46	181	949
Organic farming (1/0)	0.093	0.29	6	1124
Focus specialized (1/0)	0.53	0.5	15	1115
Precipitation (average rainfall between 1961 and 2016)	1181.63	294.21	0	1130
Temperature (average temperature between 1961 and 2016)	8.98	1.67	0	1130
Distance to town (in seconds) from the next center	972.35	722.05	4	1126
Categorical variables	*Proportion*	*Frequency*		
Perceived additional costs	0%: 0.24	0%: 250		
	1–19%: 0.69	1–19%: 719		
	≥20%: 0.07	≥20%: 78		
Expected additional costs	0%: 0.138	0%: 136		
	1–19%: 0.804	1–19%: 795		
	≥20%: 0.05	≥20%: 58		
Expected revenue loss	0%: 0.30	0%: 275		
	1–19%: 0.66	1–19%: 591		
	≥20%: 0.03	≥20%: 31		
Year 2016	0.41	470		
Year 2017	0.29	326		
Year 2018	0.29	334		
Cherries	0.13	151		
Plums	0.17	191		
Grapes	0.70	788		
French speaking region	0.24	267		
Italian speaking region	0.14	155		
German speaking region	0.63	708		

Table A4 provides an overview of perceived infestation levels for the percentage of surface in the sample cultivated with cherries and plums for the year 2017 and 2018.

Table A4. Infestation levels per year for cherries and plums: share of surface infested

	Cherries		Plums	
Perceived infestation levels	Year 2017	Year 2018	Year 2017	Year 2018
0%	80%	88%	73%	93%
1–5%	13%	11%	23%	7%
6–10%	3%	1%	4%	0%
11–15%	3%	0%	0%	0%
16–20%	0%	0%	0%	0%
21–25%	0%	0%	0%	0%
26–30%	1%	0%	0%	0%
>30%	0%	0%	0%	0%

Note: The percentages were rounded.

Table A5 presents the infestation for grapes.

Table A5. Perceived infestation levels per year for grapes: share of surface infested

	Grapes		
Infestation levels	Year 2016	Year 2017	Year 2018
0%	81%	90.4%	71%
Up to 5%	16%	7.2%	27%
Between 5% and 12.5%	3%	1.7%	1%
Between 12.5% and 25%	0%	0.4%	1%
Between 25% and 50%	0%	0.2%	0%
Between 50% and 75%	0%	0.1%	0%
Over 75%	0%	0%	0%

Note: The percentages were rounded.

Table A6 presents the results for plums for which we had different infestation scales in 2016.

Table A6. Perceived infestation levels for plums (2016): share of surface infested

Infestation levels	Plums 2016
0%	69%
1–19%	29%
>19%	2%

Note: The percentages were rounded.

Table A7 provides an overview of the number of growers obliged to abort a harvest completely due to *D. suzukii* infestation.

Table A7. Abortion of harvest per crop

Crops	Aborted	Total
Cherries (2017–2018)	14	151
Plums (2016–2018)	2	191
Grapes (2016–2018)	3	788
Total	19	1130

Note: We merged all years together for grapes, cherries, and plums.

Table A8 provides an overview of the frequency and proportion for each measure taken by growers per crop.

Table A8. Frequency and proportion of measures taken per crop

	Cherries $N = 151$		Plums $N = 191$		Grapes $N = 788$		Total $N = 1130$	
Measures	*N*	%	*N*	%	*N*	%	*N*	%
Sanitation measures	95	63	96	50	407	52	598	53%
Control for infestation	84	56	89	47	310	39	483	43%
Nets	89	59	11	6	119	15	219	19%
Mass collection	17	11	49	26	151	19	217	19%
Insecticides	99	66	94	49	157	20	350	31%
Early harvest	38	25	42	22	104	13	184	16%
No strategies	14	9	29	15	230	29	273	24%

Note: The growers could choose more than one measure.

Table A9. Correlation matrix between the dependent variables: perceived additional cost, expected additional cost and revenue loss

Variables	Perceived additional cost	Expected additional costs	Expected revenue losses
Perceived additional cost	1		
Expected additional cost	0.52***	1	
Expected revenue loss	0.24***	0.46***	1

Note: Correlation matrix for binary dependent variables. *,**, and *** denote significance at the 10%, 5%, and 1% level, respectively.

Table A10 represents the results of the OLS regression and the probit regression for perceived additional costs and the expected additional costs due to *D. suzukii*.

Table A10. Ordinary least squares (OLS) and probit: perceived additional costs and expected additional costs

	(1) Perceived additional costs OLS full specification	(2) Perceived additional costs OLS restricted specification	(3) Perceived additional costs probit	(4) Expected additional costs OLS full specification	(5) Expected additional costs OLS restricted specification	(6) Expected additional costs probit
Age	−0.05** (0.02)	−0.04** (0.01)	−0.04*** (0.01)	−0.03** (0.01)	−0.03*** (0.01)	−0.02** (0.01)
Gender (male)	0.17** (0.05)	0.20*** (0.05)	0.17** (0.07)	−0.005 (0.05)	0.08* (0.04)	−0.01 (0.04)
Risk aversion	−0.002 (0.01)	−0.01 (0.01)	−0.002 (0.01)	0.00 (0.01)	0.00 (0.01)	0.00 (0.01)
Farm size	−0.93*** (0.29)	−0.02* (0.01)	−0.98** (0.42)	0.05 (0.36)	−0.02*** (0.00)	0.05 (0.35)
Shannon Index	0.07** (0.02)	0.08*** (0.01)	0.07*** (0.01)	0.04*** (0.01)	0.06*** (0.01)	0.03*** (0.01)
Share of off-farm income	−0.04 (0.03)		−0.04 (0.03)	−0.006 (0.03)		−0.001 (0.02)
Land tenure	0.02 (0.03)		0.02 (0.03)	0.01 (0.02)		0.00 (0.02)
Organic farming	0.00 (0.04)		0.00 (0.04)	−0.11*** (0.04)		−0.11** (0.05)
Focus specialized	−0.05 (0.04)		−0.05 (0.03)	−0.22 (0.03)		−0.01 (0.03)
Year 2017	0.00 (0.03)	0.00 (0.03)	0.00 (0.03)	0.00 (0.03)	0.00 (0.02)	0.01 (0.02)
Year 2018	−0.13*** (0.03)	−0.12*** (0.03)	−0.12*** (0.04)	−0.07** (0.02)	−0.07*** (0.02)	−0.07** (0.03)
			Control variables			
Distance to town	−0.02 (0.01)	−0.02 (0.01)	−0.02 (0.01)	−0.006 (0.01)	−0.02* (0.01)	−0.001 (0.01)
Precipitation squared	−0.05 (0.13)	−0.16 (0.11)	−0.06 (0.133)	0.21* (0.11)	0.11 (0.09)	0.24** (0.12)
Precipitation	0.07 (0.12)	0.18 (0.11)	0.08 (0.125)	−0.19* (0.10)	−0.10 (0.09)	−0.23* (0.11)
Temperature	0.13* (0.07)	0.11* (0.06)	0.12* (0.07)	0.07 (0.06)	−0.02 (0.05)	0.05 (0.06)
Temperature squared	−0.17** (0.07)	−0.13** (0.06)	−0.15** (0.07)	−0.11* (0.06)	0.00 (0.05)	−0.09* (0.05)
Plums	−0.02 (0.05)	−0.03 (0.05)	−0.06 (0.07)	−0.07** (0.03)	0.02 (0.04)	0.01 (0.04)
Grapes	0.01 (0.05)	−0.01 (0.05)	−0.02 (0.06)	0.03 (0.04)	0.03 (0.04)	0.01 (0.04)
	−0.102** (0.04)	−0.1*** (0.03)	−0.11** (0.04)	−0.07** (0.03)	−0.09*** (0.03)	−0.08* (0.04)

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Table A10. Continued

	(1) Perceived additional costs OLS full specification	(2) Perceived additional costs OLS restricted specification	(3) Perceived additional costs probit	(4) Expected additional costs OLS full specification	(5) Expected additional costs OLS restricted specification	(6) Expected additional costs probit
French speaking region						
Italian speaking region	0.05 (0.07)	0.02 (0.06)	0.04 (0.06)	−0.02 (0.06)	−0.01 (0.05)	−0.03 (0.07)
Adjusted R^2	0.100	0.101	—	0.061	0.064	—
Pseudo R^2	—		0.072	—	—	0.041
Number of observations	735	924	735	703	880	703
Average VIF	1.25	1.75	1.25	1.28	1.74	1.28

Note: Standard errors are in parenthesis. *,** and *** denote significance at the 10%, 5% and 1% level, respectively. Perceived additional costs represents the additional costs estimated in percent per kilogram yield arising from the measures taken against *Drosophila suzukii*. The first column shows an OLS with perceived additional costs as the dependent variable (1/0), 0 = no perceived additional costs, 1 = perceived additional costs. The second column presents a restricted specification of the OLS, where a number of farm characteristics were not included for sensitivity tests. The third column is the probit and coefficients are marginal correlations. Expected additional costs indicates the expected additional costs estimated in percent per kilogram yield arising from the measures taken by growers against *D. suzukii*. The fourth column represents an OLS with expected additional costs as the dependent variable (1/0),0 = no expected additional costs, 1 = expected additional costs. The fifth column shows a restricted specification of the OLS, where a number of farm characteristics are not included for sensitivity tests. The sixth column represents a probit. For the average variance inflation factor (VIF), we did not include the squared variables for temperature and precipitation.

Table A11 presents the results of the OLS regression and the probit regression for expected revenue losses.

Table A11. Ordinary least squares (OLS) regression, probit regression: expected revenue loss for next harvest

	(1) Expected revenue loss OLS	(2) Expected revenue loss OLS restricted	(3) Expected revenue loss probit
Age	−0.07*** (0.02)	−0.07*** (0.01)	−0.07*** (0.02)
Gender (male)	0.07 (0.07)	0.12* (0.06)	0.08 (0.08)
Risk aversion	−0.02 (0.01)	−0.02 (0.01)	−0.02 (0.01)
Farm size	0.53 (0.56)	−0.01 (0.01)	0.58 (0.638)
Shannon Index	−0.01 (0.02)	0.00 (0.02)	−0.01 (0.02)
Share of off-farm income	0.01 (0.04)		0.01 (0.04)
Land tenure	0.04 (0.04)		0.04 (0.03)
Organic farming	−0.04 (0.05)		−0.05 (0.06)
Focus specialized	−0.01 (0.05)		−0.01 (0.05)
Plums	0.11* (0.06)	0.09 (0.06)	0.11** (0.05)
Grapes	0.15** (0.07)	0.11** (0.06)	0.16** (0.08)
Year 2017	0.07* (0.04)	0.09** (0.04)	0.07* (0.04)
Year 2018	−0.04 (0.04)	−0.02 (0.04)	−0.04 (0.04)
Control variables			
Distance to town	−0.02 (0.02)	−0.02 (0.02)	−0.02 (0.02)
Precipitation squared	0.26 (0.16)	0.17 (0.14)	0.30* (0.18)
Precipitation	−0.21 (0.15)	−0.14 (0.13)	−0.24 (0.16)
Temperature	−0.07 (0.08)	−0.13* (0.08)	−0.09 (0.10)
Temperature squared	0.04 (0.08)	0.11 (0.07)	0.06 (0.09)
French speaking region	−0.16*** (0.05)	−0.13*** (0.04)	−0.18*** (0.06)
Italian speaking region	−0.15 (0.09)	−0.11 (0.08)	−0.21* (0.12)
Adjusted R^2	0.031	0.036	—
Pseudo R^2	—		0.00
Number of observations	639	797	639
Mean VIF	1.30	1.75	1.30

Note: Standard errors are in parenthesis. *,** and *** denote significance at the 10%, 5% and 1% level, respectively. Expected revenue loss represents the expected revenue loss in percentage for the next harvest due to *Drosophila suzukii*. The first column represents an OLS with revenue loss as the dependent variable (1/0), 0 = no revenue loss, 1 = revenue losses. The second column shows a restricted specification of the OLS, where a number of farm characteristics are not included for sensitivity tests. The third column presents a probit. For the average variance inflation factor (VIF), we did not include the squared variables for temperature and precipitation.

Table A12 presents the results of the OLS regression with fewer variables as a sensitivity test.

Table A12. Factors associated with perceived additional costs, expected additional costs and expected revenue losses: sensitivity tests

	(1) Perceived additional costs OLS	(2) Expected additional costs OLS	(3) Expected revenue loss OLS
Age			
Gender (male)	0.17** (0.05)	−0.001 (0.05)	0.05 (0.07)
Risk aversion	−0.008 (0.01)	0.00 (0.01)	−0.02 (0.01)
Farm size			
Diversification (Shannon Index)	0.07*** (0.02)	0.04*** (0.01)	0.00 (0.02)
Share of off-farm income	−0.04 (0.03)	−0.02 (0.03)	−0.02 (0.04)
Land tenure	0.03 (0.03)	0.02 (0.02)	0.06 (0.04)
Organic farming	0.00 (0.04)	−0.11*** (0.04)	−0.04 (0.05)
Focus specialized	−0.04 (0.04)	−0.22 (0.03)	−0.02 (0.05)
Plums	−0.03 (0.05)	0.00 (0.03)	0.08* (0.06)
Grapes	0.00 (0.05)	0.01 (0.04)	0.11 (0.07)
Year 2017	0.00 (0.03)	0.00 (0.03)	0.07* (0.04)
Year 2018	−0.13*** (0.03)	−0.07*** (0.02)	−0.06 (0.04)
Control variables			
Distance to town	−0.02 (0.01)	0.00 (0.01)	−0.02 (0.02)
Precipitation squared	−0.05 (0.13)	0.21* (0.11)	0.24 (0.16)
Precipitation	0.07 (0.12)	−0.19* (0.10)	−0.21 (0.15)
Temperature	0.16 (0.07)	0.05 (0.06)	−0.07 (0.08)
Temperature squared	−0.16** (0.07)	−0.09* (0.06)	0.04 (0.08)
French speaking region	−0.09** (0.04)	−0.07** (0.03)	−0.14*** (0.05)
Italian speaking region	0.05 (0.07)	−0.02 (0.06)	−0.14 (0.09)
Adjusted R^2	0.083	0.061	0.031
Number of observations	756	723	656

Note: Standard errors are in parenthesis. *,** and *** denote significance at the 10%, 5% and 1% level, respectively.

Table A13 presents the results of the variance inflation factor (VIF) for all three regressions performed. We did not include the squared variables for weather as these are correlated.

Table A13. Variance inflation factor (VIF)

	Perceived additional costs		Expected additional costs		Expected revenue losses	
	VIF	1/VIF	VIF	1/VIF	VIF	1/VIF
Age	1.17	0.85	1.18	0.85	1.17	0.85
Gender (male)	1.04	0.96	1.04	0.96	1.03	0.96
Risk aversion	1.05	0.94	1.05	0.94	1.05	0.94
Farm size	1.14	0.76	1.32	0.76	1.34	0.74
Shannon Index	1.32	0.74	1.35	0.74	1.37	0.73
Share of off-farm income	1.48	0.64	1.56	0.64	1.57	0.63
Land tenure	1.05	0.94	1.06	0.94	1.06	0.94
Organic farming	1.04	0.95	1.04	0.95	1.05	0.95
Focus specialized	1.16	0.82	1.22	0.82	1.22	0.81
Distance to town	1.78	0.56	1.77	0.56	1.83	0.54
Precipitation	1.39	0.72	1.37	0.72	1.41	0.72
Temperature	1.44	0.69	1.44	0.69	1.47	0.67

Table A14 represents the results of the ordered probit regression for additional costs, expected additional costs and expected revenue losses.

Table A14. Ordered probit regression: perceived additional costs, expected additional costs and expected revenue loss for next harvest

	Perceived additional costs			Expected additional costs			Expected revenue losses		
Variables	(1) 0%	(2) 1–20%	(3) >20%	(4) 0%	(5) 1–20%	(6) >20%	(7) 0%	(8) 1–20%	(9) >20%
Age	0.04*** (0.01)	−0.01*** (0.00)	−0.02*** (0.00)	0.02** (0.01)	−0.01** (0.00)	−0.01** (0.00)	0.05** (0.01)	−0.04*** (0.01)	−0.01** (0.00)
Gender (male)	−0.09** (0.04)	0.04** (0.02)	0.05** (0.02)	0.03 (0.04)	−0.015 (0.01)	−0.02 (0.02)	−0.06 (0.06)	0.04 (0.05)	0.00 (0.01)
Risk aversion	0.01 (0.01)	−0.00 (0.00)	−0.00 (0.00)	0.00 (0.01)	−0.00 (0.00)	−0.00 (0.00)	0.01 (0.01)	−0.01 (0.01)	−0.00 (0.00)
Farm size	0.98*** (0.35)	−0.48*** (0.1)	−0.50*** (0.19)	0.16 (0.30)	−0.06 (0.144)	−0.09 (0.16)	−0.65 (0.51)	0.51 (0.41)	0.13 (0.1)
Shannon Index	−0.05*** (0.01)	0.02*** (0.00)	0.02*** (0.00)	−0.03** (0.01)	0.01** (0.00)	0.01** (0.00)	0.03 (0.02)	−0.02 (0.01)	−0.00 (0.00)
Share of off-farm income	0.03 (0.03)	−0.01 (0.01)	−0.01 (0.01)	−0.01 (0.02)	0.00 (0.01)	0.00 (0.01)	−0.00 (0.04)	0.00 (0.03)	0.00 (0.00)
Land tenure	−0.01 (0.02)	0.01 (0.01)	0.00 (0.01)	0.00 (0.02)	−0.00 (0.01)	−0.00 (0.01)	−0.02 (0.03)	0.01 (0.02)	0.00 (0.00)
Organic farming	0.01 (0.04)	−0.00 (0.02)	−0.00 (0.01)	0.09*** (0.03)	−0.04*** (0.01)	−0.05*** (0.19)	0.06 (0.05)	−0.05 (0.04)	−0.00 (0.00)
Focus specialized	0.05 (0.03)	−0.03 (0.01)	−0.02 (0.01)	0.03 (0.02)	−0.01 (0.01)	−0.02 (0.01)	0.02 (0.04)	−0.02 (0.04)	−0.00 (0.00)
Plums	0.00 (0.04)	0.00 (0.02)	0.00 (0.02)	−0.01 (0.03)	0.00 (0.01)	0.00 (0.01)	−0.03 (0.06)	0.02 (0.05)	0.00 (0.00)
Grapes	0.01 (0.05)	−0.00 (0.02)	−0.00 (0.02)	−0.01 (0.04)	0.00 (0.19)	0.00 (0.02)	−0.05 (0.06)	0.04 (0.06)	0.01 (0.01)
Year 2017	0.05 (0.03)	−0.02 (0.17)	−0.02 (0.1)	0.01 (0.02)	−0.00 (0.01)	−0.01 (0.01)	−0.06* (0.04)	0.05* (0.03)	0.01 (0.00)
Year 2018	0.16*** (0.02)	−0.08*** (0.01)	−0.07*** (0.01)	0.08*** (0.02)	−0.03*** (0.01)	−0.04*** (0.01)	0.03 (0.04)	−0.03 (0.03)	−0.00 (0.00)
Control variables									
Distance to town	0.02 (0.01)	−0.01 (0.00)	−0.01 (0.00)	0.00 (0.01)	−0.00 (0.00)	−0.00 (0.00)	0.02 (0.02)	−0.01 (0.01)	−0.00 (0.00)
Precipitation squared	0.17 (0.08)	−0.07 (0.04)	−0.05 (0.05)	−0.20** (0.09)	0.08* (0.04)	0.11** (0.05)	−0.25* (0.15)	0.20* (0.12)	0.05 (0.03)
Precipitation	−0.12 (0.10)	0.06 (0.05)	0.10 (0.04)	0.17* (0.08)	−0.07* (0.04)	−0.10* (0.05)	0.20 (0.14)	−0.16 (0.11)	−0.04 (0.03)
Temperature	−0.12** (0.05)	0.06** (0.03)	0.05** (0.02)	−0.05 (0.04)	0.02 (0.02)	0.03 (0.02)	0.02 (0.08)	−0.02 (0.07)	−0.00 (0.01)
Temperature squared	0.15** (0.05)	−0.08** (0.03)	−0.07** (0.02)	0.09* (0.04)	−0.04* (0.02)	−0.05* (0.02)	−0.01 (0.08)	−0.01 (0.07)	−0.00 (0.01)
French speaking region	0.06* (0.03)	−0.03* (0.01)	−0.03* (0.01)	0.05** (0.02)	−0.02* (0.01)	−0.03* (0.01)	0.11** (0.04)	−0.09** (0.04)	−0.02** (0.01)
Italian speaking region	−0.04 (0.06)	0.02 (0.03)	0.02 (0.02)	0.04 (0.05)	−0.19 (0.02)	−0.02 (0.02)	0.12 (0.09)	−0.09 (0.07)	−0.02 (0.01)
Adjusted R^2	0.09	0.09	0.09	0.08	0.08	0.08	0.04	0.04	0.04
Number of observations	735	735	735	703	703	703	639	639	639

Note: Coefficients are marginal correlations. Standard errors are in parenthesis. *,** and *** denote significance at the 10%, 5% and 1% level, respectively. Perceived additional costs represents the perceived additional costs estimated in percent per kilogram yield arising from the measures taken against *Drosophila suzukii*. The first three columns present the dependent variable with three categories (no perceived additional costs, 1–20% perceived additional costs, >20% perceived additional costs). The fourth column to the sixth column presents the dependent variable with three categories (no expected additional costs, 1–20% expected additional costs, >20% expected additional costs). The seventh column to the ninth columns shows the ordered probit with three different categories of revenue losses as the dependent variable: 0% costs, 1–20% loss, >20% losses.

Table A15 presents summary statistics on the use of measures per gender in our sample.

Table A15. Measures taken per gender

Gender		Preventive measures	Control for infestation	Early harvest	Insecticides	Mass collection	Nets	No strategies	Total *N*
Female	*N*	31	32	13	17	13	12	24	82
	%	38	39	16	21	16	15	29	
Male	*N*	555	440	168	327	201	199	231	1009
	%	55	44	17	32	20	20	23	

Note: Growers could choose more than one measure.

Figure A1 provides an overview of infestation levels per crop and per year. Infestation levels for cherries were only available for 2017 and 2018. Infestation scale for plums was different in 2016. The results for plums in 2016 are presented in Fig. A2.

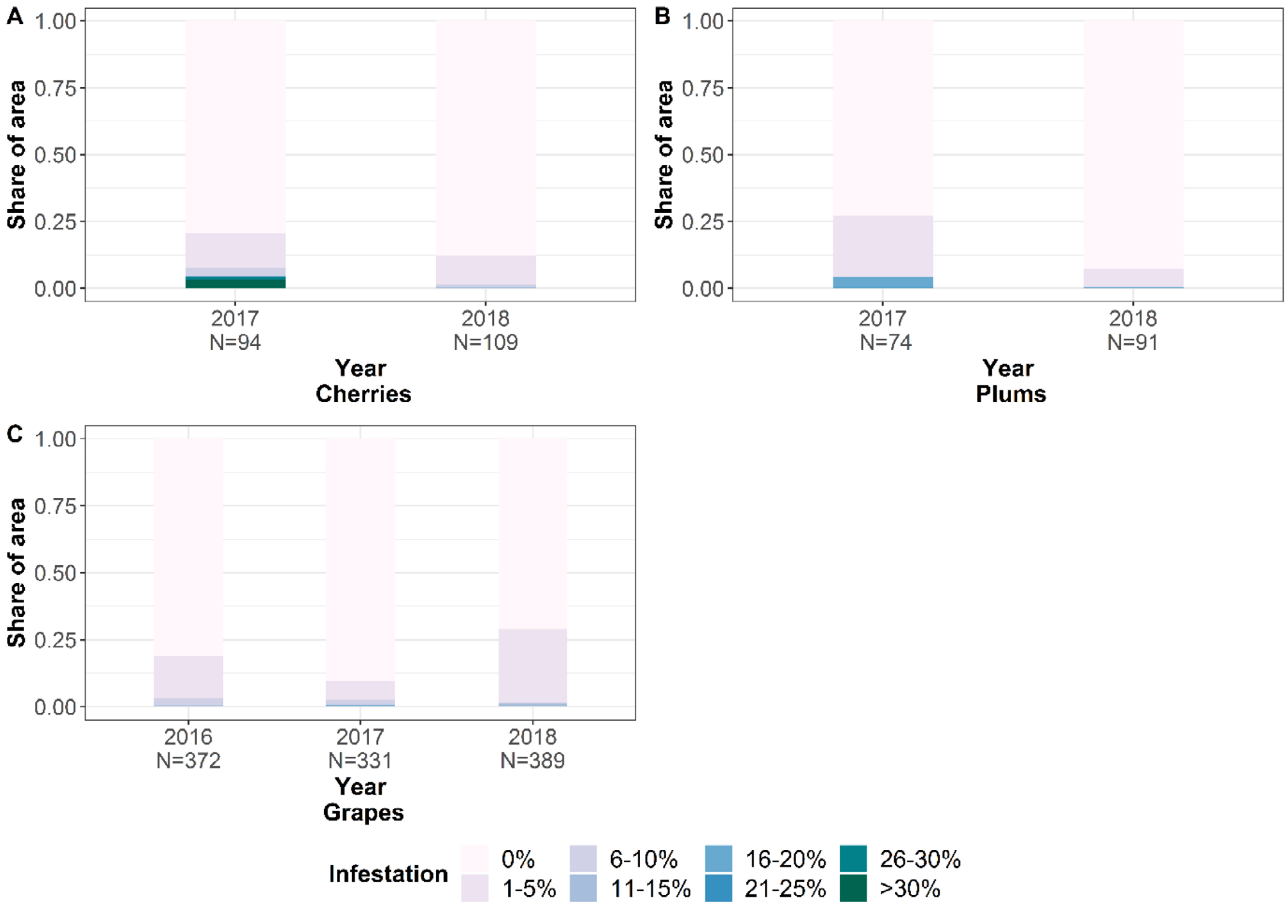

Figure A1. Perceived infestation levels per crop per year. Note: The infestation scale for plums in 2016 was different from 2017 and 2018. In 2017 and 2018, we decided to make the scale larger due to the very small variance in 2016. Therefore, we did not include plums (2016) above. We did not collect data for cherries in 2016, therefore no data is presented for cherries in that year.

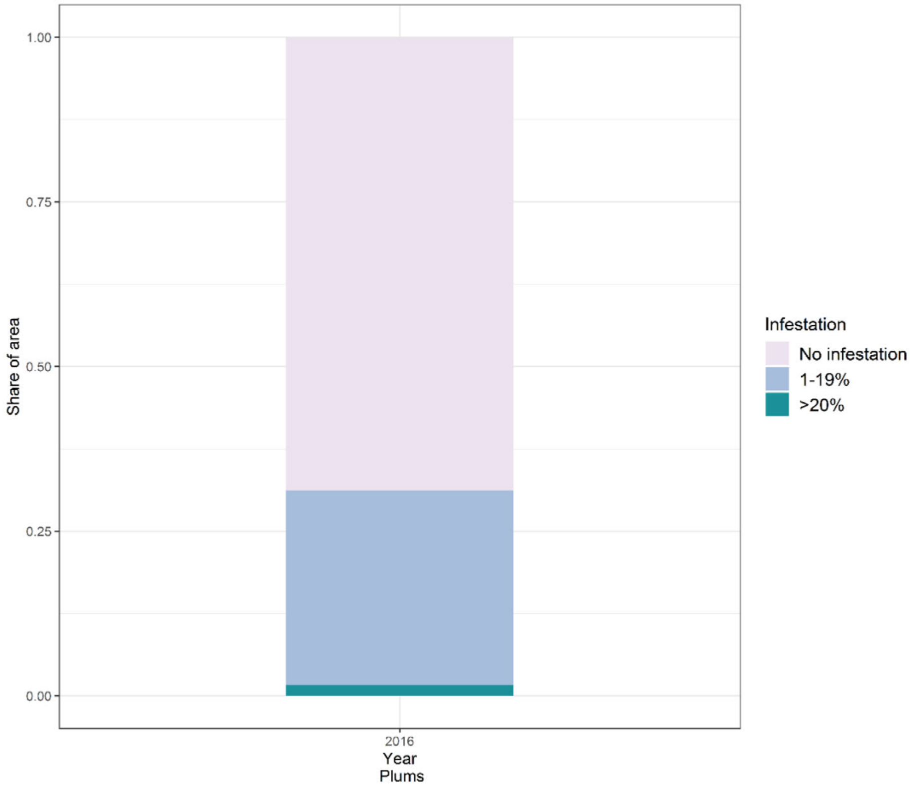

Figure A2. Perceived infestation levels for plums (year 2016). Note: The infestation scale for plums in 2016 was different from 2017 and 2018. In 2017 and 2018, we decided to make the scale larger due to the very small variance in 2016.

Figure A3 presents measures taken per year per crop against the *D. suzukii*. Viewed from the crop level, measures taken are quite similar from 1 year to the next.

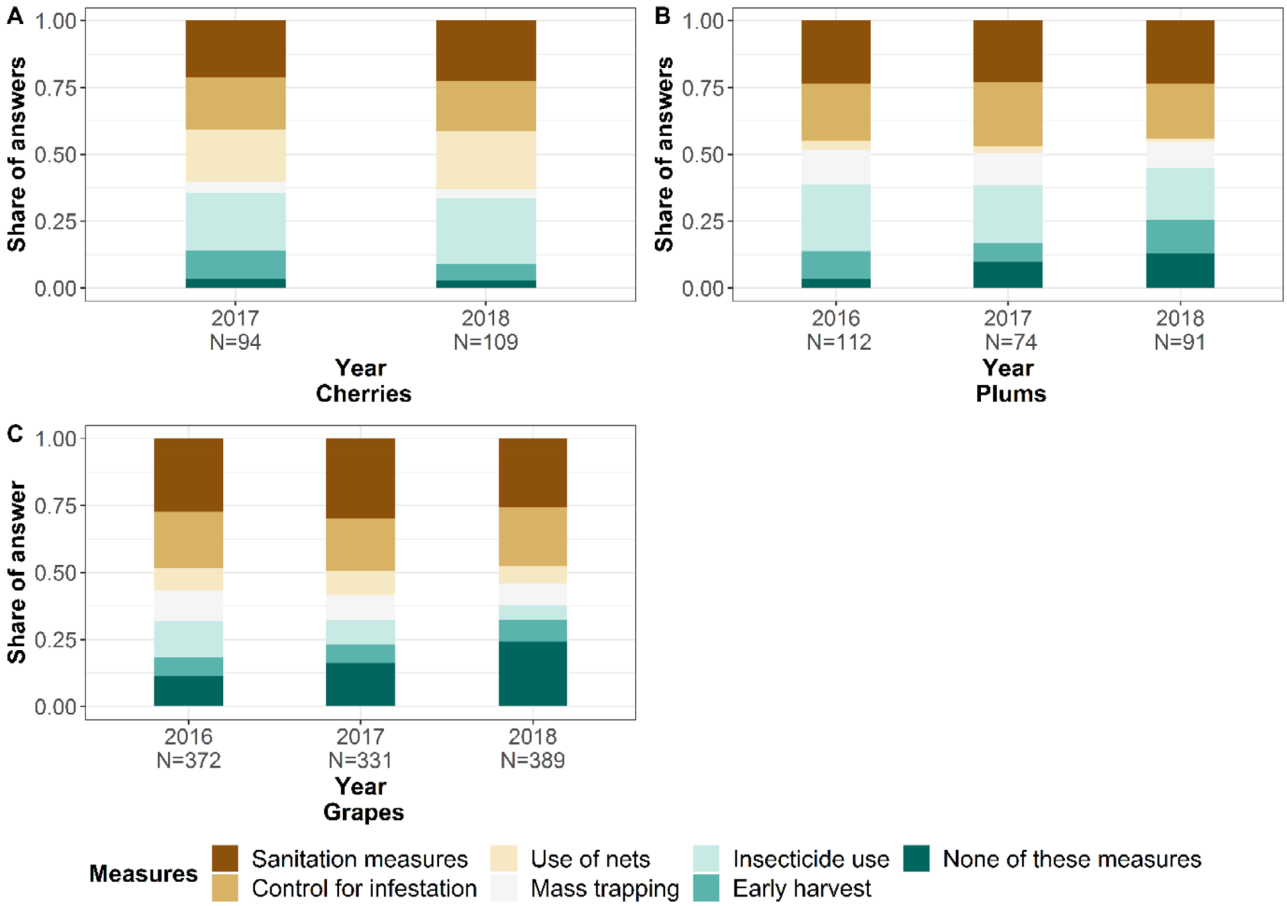

Figure A3. Measures taken per year per crop. Note: Kaolin is a biological insecticide, which is included in the category of insecticides for cherries and grapes. Control for infestation refers to measures where the fruit growers controls whether the *Drosophila suzukii* is present on the field of the fruit grower or not. At a certain threshold, more specifically when a certain amount of *D. suzukii* is found on the field, the fruit grower in Switzerland can then use a given regulated amount of insecticides on their field. To control for infestation, fruit growers can use (i) visual control, by going on the field and checking if there are any signs of infestation, (ii) binocular control, by using a binocular of magnifying glass to control for eggs, (iii) special units control where specialists from the regional cantonal advisory services come to the field and inspect for infestation, (iv) trap control, where fruit growers can put traps in the field in order to check whether there are any *D. suzukii* in the field, (v) salt control which is when the fruit grower harvests the fruits and puts them in water with salt to control for larvae of *D. suzukii*.

Figure A4 illustrates the expected additional costs due to *D. suzukii* in 2016. The scale used in 2016 for the expected additional costs differed from the scale used in 2017 and 2018. Therefore, we present the figures separately.

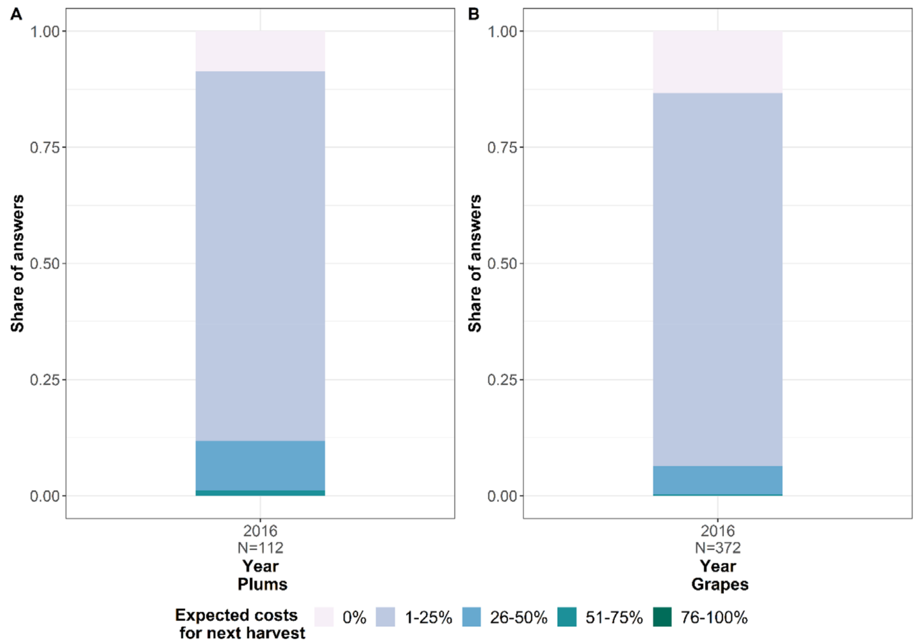

Figure A4. Expected additional costs for the next harvest of crops (Data 2016). Note: The scale for expected additional costs for the next plum and grape harvests due to *Drosophila suzukii* in 2016 differed from the scale used in 2017 and 2018. In 2017 and 2018, we decided to make the scale larger due to the very small variance in 2016.

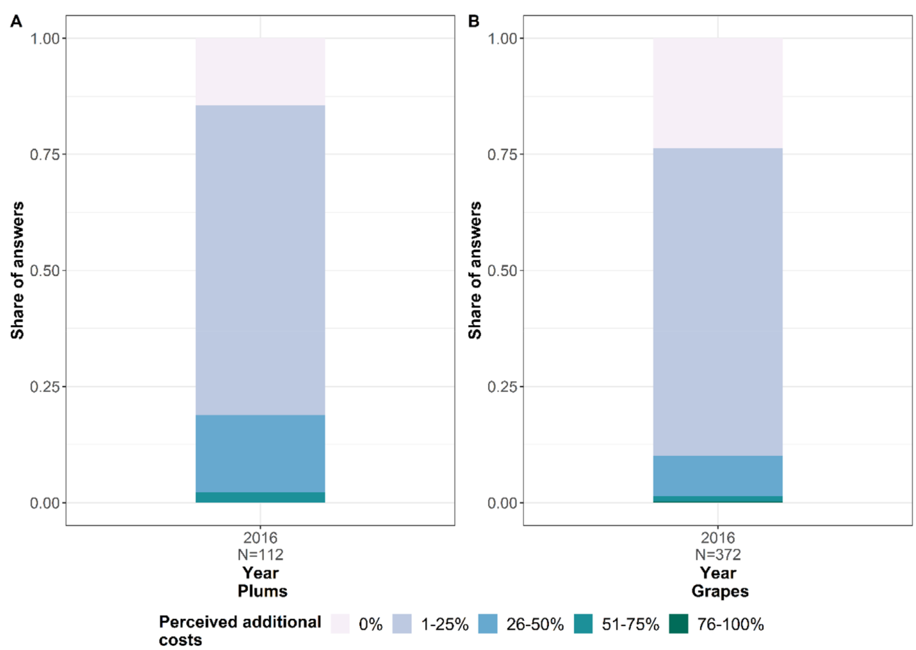

Figure A5. Perceived additional costs due to *Drosophila suzukii* infestation (2016). Note: The scale for perceived additional costs due to *D. suzukii* for plums and grapes in 2016 differed from 2017 and 2018. In 2017 and 2018, we decided to make the scale larger due to the very small variance in 2016.

Figure A6 illustrates the expected revenue loss due to *D. suzukii* in 2016. The scale used in 2016 for the expected revenue loss differed from the scale used in 2017 and 2018. Therefore, we present the figures separately.

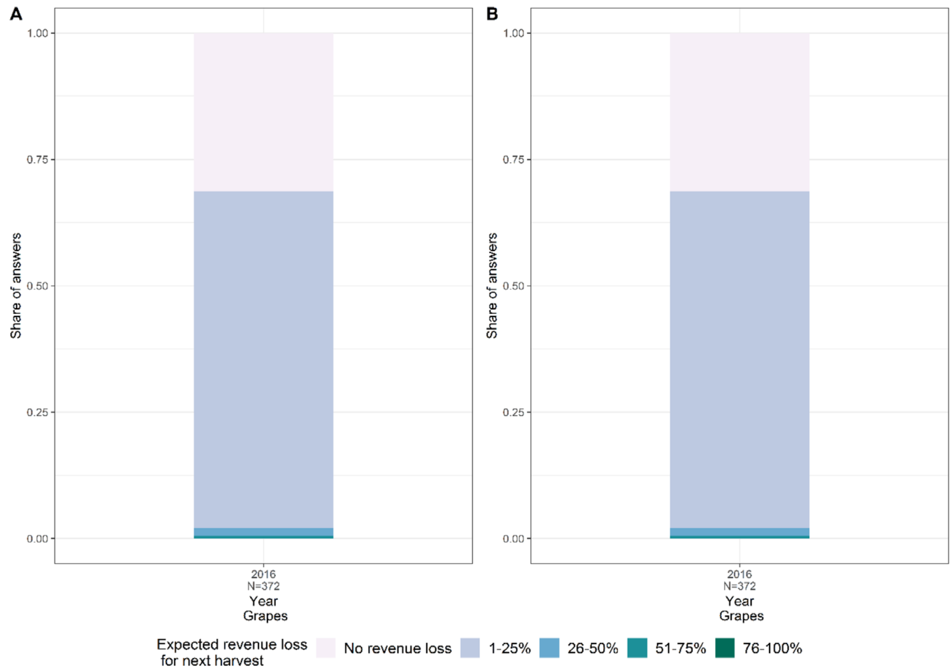

Figure A6. Expected revenue loss due to *Drosophila suzukii* infestation (2016). Note: The scale for expected revenue loss due to *D. suzukii* for plums and grapes in 2016 differed from the scale used in 2017 and 2018. In 2017 and 2018, we decided to make the scale larger due to the very small variance in year 2016.

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