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Results of the farm survey about preferred control options

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Abstract
<p>D5.3 presents the results of a multi-country survey conducted among 420 plant and tree nurseries in Italy, Romania, Germany, and France. Although nurseries are not mandated to inspect incoming plant consignments for intra-EU trade, they have a direct interest in ensuring pest-free plant material, as infestations can be economically and reputationally costly. The objective of the survey was to assess current phytosanitary inspection practices and the adoption potential of a novel Volatile Organic Compound (VOC) sensor technology for pest and pathogen detection. The survey explores how nursery operators value certain attributes of a hypothetical VOC sensor, including time to results, detection reliability, cost per inspection, certification potential, and ownership model. D5.3 presents both descriptive insights of nursery and socio-demographic characteristics, current phytosanitary practices, perceptions of responsibility and trust among different actors involved in plant health, and the results of a discrete choice experiment (DCE). In the DCE, respondents chose between two hypothetical VOC sensor configurations and a status quo option representing their current inspection practice (non-adoption). The number and composition of choice cards were statistically determined using a D-efficient design. We analyzed the DCE responses using a mixed logit model. Nurseries appear to prefer VOC-based sensor detection tools that provide faster results, higher detection reliability, and lower inspection costs. The cost per inspection attribute was consistently the most important factor discouraging adoption, while reliability and speed were positively valued. Preferences for certification potential varied, and the ownership of the VOC sensor showed no evident effect on adoption decisions. Overall, this study suggests that adoption of a VOC sensor will depend on its affordability, diagnostic performance, and perceived added value.</p>

Public introduction ¹
<p>The nursery industry can play a key role in preventing the spread of harmful pests and pathogens through plant trade. Although nurseries are not required to re-inspect plant consignments once they enter the EU internal market, they have a strong interest in ensuring that the plants they buy and sell are pest-free.</p> <p>The PurPest project surveyed 420 nurseries in Italy, Romania, Germany, and France. The study examined how nurseries inspect incoming plants, their experience with invasive pests and pathogens, and their views on responsibility and trust among different actors involved in plant health. The survey also introduced a novel detection tool, a Volatile Organic Compound sensor, and asked respondents to choose between different versions of this sensor and their current inspection practice.</p> <p>This deliverable examines what European nurseries value in a new pest and pathogen detection technology and what barriers may influence their adoption decisions. The findings support the development of reliable and cost-effective detection tools that can reinforce EU biosecurity and inform plant health policy efforts.</p>

¹ According to Deliverables list in Annex I, all restricted (RE) deliverables will contain an introduction that will be made public through the project WEBSITE

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1 INTRODUCTION

Human activity, such as travel and trade, and climate change, have been increasingly transgressing the natural barriers that once constrained the dispersal of biota (Capinha et al., 2015). As a result, an ever-growing number of alien species are establishing populations outside their native range (Seebens et al., 2017; Pyšek et al., 2010; Hulme et al., 2009; Hulme, 2009). Among these are invasive plants, animals, plant pests, and pathogens, whose introductions can generate profound ecological, economic, and social impacts (Simberloff et al., 2013). Global trade networks involving nurseries facilitate the movement of plants, plant parts, and other plant-related products, and represent a major long-distance pathway for the spread of invasive pests and pathogens (Chapman et al., 2017; Eschen et al., 2015; Migliorini et al., 2015; Liebhold et al., 2012). The threat posed by these organisms extends beyond ornamental species to agricultural crops and forest ecosystems (Paini et al., 2016; Parke & Grünwald, 2012). A prominent recent example in Europe is the plant pathogenic bacterium *Xylella fastidiosa* (Frem et al., 2020). First intercepted in France in 1989 on grapevine propagation material imported from Italy and originally sourced from the USA, *X. fastidiosa* was formally detected in Italy in 2013 (Saponari et al., 2013; EPPO, 1989)². The pathogen is now present in Italy, Spain, France, and Portugal, and can infect at least 727 documented host plant species (Cavaliere et al., 2025). Yield reductions of approximately 78%, 16% and 5% have been reported for olive, citrus, and grapevine, respectively, across Europe and Mediterranean regions (Cardone et al., 2022). Economic losses for Italian olive production alone are estimated between €1.9-5.2 billion over 50 years (Schneider et al., 2020), while the European Commission warns of potential annual production losses of €5.5 billion across the EU, affecting 70% of the Union's olive production value and jeopardizing nearly 300 000 jobs (European Commission, n.d.). Despite preventive measures in place, the pathogen's further spread remains likely due to the continued and increasing movement of plant material and the inadvertent transport of its insect vectors (Frem et al., 2020).

To prevent the introduction of harmful organisms, plants and plant products imported into the EU are subject to phytosanitary inspections at border control posts. These inspections verify that consignments comply with import requirements and are accompanied by an official phytosanitary certificate, as stipulated by Regulation (EU) 2016/2031, the backbone of the EU's plant health regime (European Commission, 2016).³ Inspection frequency is determined on a risk basis, prioritizing high-risk plants and origins, while many shipments receive only documentary and identity checks (European Commission, 2019a, 2017).

With the adoption of the EU Single Market Act, phytosanitary controls between Member States were abolished in 1993, and phytosanitary certificates are no longer required for intra-EU movement of plants or plant material (Black & Bartlett, 2020; European Union, n.d.). Once a consignment passes border inspection, the phytosanitary certificate originally issued by the exporting country may be replaced by an EU plant passport, allowing free movement within the "internal market" (European Commission, 2016). Although plant passports provide traceability and a harmonized framework for compliance with EU phytosanitary standards, re-inspection of

² After unconfirmed reports of its presence in Kosovo (EPPO, 1998).

³ Along with Regulation (EU) 1143/2014 "on the prevention and management of the introduction and spread of invasive alien species" (European Commission, 2014). The practical implementation of these border checks is governed by Regulation (EU) 2017/625, which details how competent authorities must carry out sampling, documentation, and physical inspections at border control posts (European Commission, 2017). The specific quarantine pests, host commodities, and technicalities on import conditions are harmonized across Member States under Commission Implementing Regulation (EU) 2019/2072 (European Commission, 2019b).

plant material within the Union is not mandated. As a result, consignments that passed border controls may continue circulating even when infested, particularly as phytosanitary inspections, especially visual ones, are not fully effective or efficient (Esfandi et al., 2024; IPCC Secretariat, 2024; Liebhold et al., 2012). Infestations may be latent or asymptomatic, temporarily suppressed by fungistatic treatments, or caused by unknown or unregulated pathogens that plant inspectors may fail to recognize (Parke & Grünwald, 2012). Moreover, phytosanitary inspections inevitably rely on evaluating only a small number of sampled plants under a limited time, which adds further pressure for EU biosecurity (Eschen et al., 2015; Liebhold et al., 2012).

Notably, recent audits reveal that sampling intensity and practical implementation of the plant passport system vary substantially among EU Member States, with shortcomings identified in the registration, supervision, and inspection of authorized operators (European Commission, 2025; Eschen et al., 2015). This heterogeneity could mean that the phytosanitary assurance is not uniform across the EU, regardless of formal compliance.

Consequently, phytosanitary assurance increasingly depends on actors involved in plant trade post-border entry, such as nurseries. Nurseries have a direct interest in pest-free plant material, as infestations carry economic and reputational costs. Swedish forest plant nurseries emphasize that intensive and regular monitoring is essential to ensure early detection and damage prevention (Keskitalo et al., 2018). Furthermore, stakeholders involved in EU plant health highlight that plants traded via e-commerce, either B2B or B2C, often bypass control systems and call for the development and adoption of specific provisions for carrying out official controls for such channels (Soto-Embodas et al., 2021). Across Europe, plant health practitioners report the need for faster and accessible diagnostic tools to support on-site decision-making, as an increased hesitancy in using chemical control methods becomes prevalent. Examples of such tools include low-cost and rapid in-situ tests, particularly for *Phytophthora* spp. and *X. fastidiosa*, such as non-destructive barcoding approaches, and electronic noses (Green et al., 2023). This aligns with broader calls for appropriate tools to identify, prevent, and monitor invasive species and improve early warning methods (Jactel, 2023).

In practice, nurseries rely primarily on visual inspection, and when necessary, laboratory assays such as PCR, for the phytosanitary assessment of incoming plant consignments. Although these methods remain the standard for verifying the phytosanitary status of plant material, visual inspections have limited accuracy, while molecular tests are slower, costly, and destructive. These constraints underscore the need for a portable, non-invasive, and reliable detection tool that can be deployed directly at the point of interest. Volatile organic compound (VOC)-based technologies offer such potential. Plants emit a diverse array of VOCs, which often increase when they are physiologically stressed or infected (Gan et al., 2023; Dicke et al., 2009). Likewise, pests and pathogens themselves produce VOCs as a means of communication or metabolic by-products (Favaro et al., 2024). The resulting chemical signatures arising from plant-pest interactions can be used to identify the presence of a target organism (Fundurulic et al., 2023; Cui et al., 2018). A portable VOC-sensing “e-nose” could therefore enable nurseries to screen incoming batches more effectively, reducing reliance on outsourced laboratory testing and supporting more proactive plant health management (Cheng et al., 2021).

To this end, we conducted a multi-country survey to assess nurseries’ adoption potential of a VOC sensor-based detection technology and to estimate their willingness to pay (WTP) for such tool(s). The survey instrument included questions on nursery and operator characteristics, current detection practices, perceptions of responsibility and trust of actors involved in plant health, and a discrete choice experiment (DCE). A total of 420 complete responses were collected from nurseries in Italy, Romania, Germany, and France.

This deliverable is structured as follows: **Section 2** presents the experimental design; **Section 3** describes the theoretical framework of the DCE; **Section 4** presents details on the questionnaire sections and on the survey administration; **Section 5** reports the results; **Section 6** provides concluding remarks, followed by the **Appendix**.

2 EXPERIMENTAL DESIGN

We designed a DCE to investigate the preferences of European nursery operators for adopting a novel pest and pathogen detection technology, the VOC sensor. **Table 1** provides an overview of the five chosen attributes and their levels.

Table 1. Attributes and attribute levels used in the discrete choice experiment.

Attribute	Description	Attribute levels
Time to receive results	How long does it take to receive the inspection results	1 hour 2 hours 4 hours
Detection reliability	Likelihood that the VOC sensor correctly detects infested plants/plant material	70% 85% 95%
Cost per inspection⁴	Costs to inspect one batch (regardless of size, regardless of ownership) ⁵	€2 €4 €6 €8 €10
Certification potential	Whether the nursery can certify that the plant consignment was further inspected and declared free from pests or pathogens	Yes No
Ownership of the technology	How the nursery accesses the VOC sensor technology	Purchased (owned individually) Co-owned (e.g., with other nurseries) Outsourced (service provided by a contractor)

The attributes included in the DCE were selected to reflect relevant characteristics that nursery operators are expected to consider when deciding whether to adopt a VOC sensor as an inspection method. As direct evidence on VOC sensor adoption in nurseries is scarce, attribute selection was informed by broader strands of literature on technology adoption and insights gained from stakeholder consultations and survey pretests.

DCE designs are statistically determined, as the full factorial of attribute-level combinations would generate an infeasible number of choice sets. To address this, we employed a D-efficient fractional design, which identifies a subset of choice tasks sufficient for parameter identification, while minimizing attribute correlation, as well as cognitive load and completion time for the respondent. The design was generated using the *dcreate* module in Stata 18.5, which starts the utility function underlying the conditional logit model (Hole, 2017). The *dcreate* function generates a covariance matrix holding all possible combinations of the attributes and their levels

⁴ The “Cost per inspection” (€2-€10) is estimated assuming regular sensor use (e.g., 8 inspections/day, 5 days/week) over a 10-year life span. This estimate includes the sensor’s initial investment costs (€35.000) and annual maintenance costs (€1.000), but excludes labor costs. In the case of outsourced service provision, the same range reflected the fee paid per inspection (inclusive of operating costs, but excluding initial investment and maintenance).

⁵ For the purposes of this survey, a “batch” can refer to any incoming plant consignment, such as a pallet or container.

(full factorial design). Then, a starting design is drawn equal to the full factorial matrix. The levels within the starting design systematically change using the modified Fedorov algorithm (Carlsson & Martinsson, 2003; Zwerina et al., 1996; Cook & Nachtsheim, 1980) until no further improvement in D-efficiency is achievable (Hole, 2016). All attributes were treated as categorical to allow for non-linear effects across levels.

The final design had a D-efficiency score of 97%, which is above 90% and therefore considered to be sufficiently good (Auspurg & Hinz, 2015). The design comprised sixteen choice cards, divided into two blocks, with each respondent completing eight choice tasks. The decision to limit respondents to eight choice tasks was made in consultation with the market research company, considering both the approximate survey length of approximately 15 minutes and the risk of respondent fatigue, when evaluating alternatives with five attributes, leading to decreased response efficiency (Johnson et al., 2013). Each choice task presented respondents with two hypothetical VOC sensor configurations and a status quo alternative. As the VOC sensor was still under development at the time of the present survey, we assumed that nurseries had not yet adopted such technology; thus, the status quo option represented current inspection practices. Following the DCE part of the questionnaire, respondents were asked whether they currently perform inspections at their nursery. **Figure 1** provides an example of one of the choice cards used in the survey.

Please consider each option carefully and choose the one that would best fit your nursery's needs. There is no right or wrong choice. However, we ask you to answer as realistically as possible, as if these options were available to you.











Attribute	Option 1	Option 2	Current practice (status quo)
Time to receive results			Would rather stay in the current situation
Detection reliability			
Cost per inspection			
Certification potential			
Ownership of the technology			
Your choice	<input type="radio"/>	<input type="radio"/>	

Figure 1. Example of a choice card (English version).

3 THEORETICAL FRAMEWORK

The nursery operators' preferences toward alternative VOC sensor configurations were elicited through a DCE based on random utility theory (McFadden, 1974). The underlying assumptions of DCE are presented in detail by Hensher et al. (2015) and are briefly reiterated in this section. A respondent (n) is assumed to select an alternative (j) from a set of different alternatives (J) presented on a hypothetical choice occasion (t) that maximizes their utility (U_{njt}) (Train, 2009). The utility of each alternative can be divided into an observable component (V_{njt}) and an unobservable and independently and identically distributed random component (ε_{njt}). The k configurations of the VOC sensor (attributes) are included in the vector x_{njt} of the observable component of the utility. The influence of the attributes is assumed to be a linear function and is described by the vector β_n representing the respondent-specific coefficients (**Eq. 1**):

$$U_{njt} = V_{njt} + \varepsilon_{njt} = \beta_n x_{njt} + \varepsilon_{njt} \quad (1)$$

The conditional logit model represents the simplest form of this framework, assuming homogeneous preferences across respondents ($\beta_n = \beta$ for all n). In this setting, the predicted probability of the logit (L_{njt}) of choosing the alternative j (VOC sensor configuration) on the choice occasion t is given by (**Eq. 2**):

$$L_{njt}(\beta) = \frac{e^{\beta x_{njt}}}{\sum_{j=1}^J e^{\beta x_{njt}}} \quad (2)$$

To allow for preference heterogeneity, the more advanced mixed logit model assumes that coefficients β_n vary across respondents and are continuously distributed. The distribution of the coefficients is described as $f(\beta_n|M)$, where M represents the moments of the distribution. The unconditional probability of choosing a particular VOC sensor configuration becomes an integral over β_n values (**Eq. 3**):

$$P_{nj} = \int L_{nj}(\beta_n) f(\beta_n|M) d\beta_n \quad (3)$$

The mixed logit model has no closed form and is therefore approximated by simulation, performing random draws (Greene & Hensher, 2003). ASC equals one if one of the alternatives representing a VOC sensor configuration was chosen, and zero in case of non-adoption (opt-out option) (Auspurg & Liebe, 2011).

The mixed logit model allows for the estimation of WTP measures, defined as the marginal rate of substitution between a non-monetary attribute (β_k) and the monetary (cost) attribute (β_c) (**Eq. 4**):

$$WTP_k = -\frac{\beta_k}{\beta_c} \quad (4)$$

Positive WTP values indicate the additional amount of money respondents are willing to pay for an improved attribute level, while negative values reflect the discount required for a less favorable level. In models without individual-specific coefficients, the WTP for marginal changes in an attribute is calculated as the ratio of the coefficient on that attribute divided by the coefficient for cost. In contrast, in models with individual-specific coefficients, like the mixed logit model, calculating the ratio directly would lead to unreasonably high WTP estimates. Hence, the cost coefficient is considered fixed (Train & Weeks, 2005).

4 DATA

4.1 Survey instrument (Questionnaire)

The online questionnaire was structured into five main components. The first part (A) gathered standard information on nursery characteristics, including respondents' role, years of operation, nursery size, and the main types of plants cultivated or sold. The second part (B) introduced the DCE. Prior to completing the eight choice tasks, respondents were presented with a description of the VOC sensor, a figure including a mock-up design of the VOC sensor, a table with the attributes and attribute levels, and a short “cheap talk” script encouraging realistic answers. To contextualize the cost attribute, they were informed that the VOC sensor would cost approximately €35,000, with a two-year warranty and annual maintenance of €1,000. Immediately after the DCE, a follow-up question addressed potential attribute non-attendance. The third part (C) asked about respondents' experience with invasive pests and pathogens, while the fourth part (D) focused on their opinions of existing detection methods and their perceptions of responsibility and trust among relevant actors in plant health. The final part (E) collected socio-demographic information. The complete questionnaire is provided in the **Appendix**.

4.2 Survey administration and sample

The survey was implemented with the aid of a professional market research company, selected after a competitive procurement process. In total, 24 market research companies were contacted via email, most of which were listed in the [ESOMAR](#) directory. Eight provided detailed quotes, while one declined to participate due to feasibility constraints. The final provider was chosen based on four evaluation criteria: (i) geographic coverage, i.e., the number and geographic distribution of the targeted countries; (ii) sample size relative to budget, meaning the number of responses offered within the given budget and the efficiency of the quote in terms of cost per completed survey; (iii) methodological fit, in particular the capacity to conduct an the survey online, as it embedded a figure and choice cards; and (iv) timeline feasibility, i.e., the ability to deliver the results by September 2025. The process of soliciting and reviewing the quotes received began in May 2025, and data collection was carried out from July to September 2025. The selected market research company was commissioned to deliver a sample representative of the nursery sector in each of the targeted countries. A total of 420 complete and valid responses were collected across four MSs: Italy ($n = 100$), Romania ($n = 80$), Germany ($n = 130$), and France ($n = 110$). In addition, 269 incomplete responses were registered but excluded from the final dataset and analysis.

Note: During data validation, an issue was identified in the programming of the DCE, caused by the incorrect implementation of the randomization logit by the subcontracted market research company. As this issue affected only the DCE section and could not be corrected retrospectively, the experiment was re-administered in November 2025 to the same participant pool. The follow-up survey included only choice cards and achieved an 81% response rate, resulting in 343 valid DCE responses (as opposed to the initial 420 sample): Italy ($n' = 81$), Romania ($n' = 66$), Germany ($n' = 106$), and France ($n' = 90$). Thus, sub-section 5.5 is based on the sample derived from the follow-up survey ($n' = 343$), while the rest of this deliverable is on the original sample ($n = 420$).

The DCE results derived from the analysis of the follow-up survey data exhibit the expected signs and statistical significance across most attributes. In particular, the central monetary attribute, cost per inspection, shows a negative and statistically significant effect

on choice probabilities, consistent with economic theory.⁶ The estimated preference structure across attributes aligns with prior hypotheses, confirming the internal validity of the dataset and the robustness of the results. A detailed description of the identified error and the diagnostic checks performed is provided in the Appendix, and was shared with the subcontracted market research company.

⁶ Notably, in the first survey round, results were largely counterintuitive and inconsistent: e.g., the cost does not play any role in the adoption decisions and had a positive sign, suggesting that the more expensive the VOC sensor, the more likely to adopt.

5 RESULTS

This section presents the results of the survey and the DCE conducted among nursery operators in Italy, Romania, Germany, and France. Firstly, we report descriptive statistics on sample composition, nursery characteristics, current practices, and attitudes toward pest detection methods. These results provide context on the operational environment of nurseries and their prior experiences with invasive pests and pathogens. Secondly, we present the results of the DCE on the adoption of VOC sensors. The DCE results are based on a mixed logit model.

5.1 Sample characteristics

Across the total sample, most respondents were male (60%), between 25 and 56 years of age (77%), with about two-thirds holding a bachelor's degree or higher (

Table 2). Notable cross-country differences were observed in association membership, defined as being part of a nursery association (e.g., European Nurserystock Association). Membership rates exceeded 90% in Italy, Germany, and France, but were markedly lower in Romania (15%). Lastly, the financial position of the nurseries varied substantially, with approximately 40% of nurseries characterizing their situation as “very good (room for investments)” or “good (sufficient reserves)”, one-third as “medium (profitable but with considerable debt)”, and roughly 10% as “low (profitability varies, high indebtedness)” or “bad (structurally loss-making)”.

Table 2. Socio-demographic characteristics of nursery operators in the survey sample.

		Total	Italy	Romania	Germany	France
Gender	Female	39.0%	43.0%	33.8%	38.5%	40.0%
	Male	60.2%	57.0%	63.8%	60.8%	60.0%
	Other / Prefer not to say	0.7%	0.0%	2.5%	0.8%	0.0%
Age	18-24	7.1%	6.0%	0.0%	9.2%	10.9%
	25-34	21.4%	21.0%	26.3%	20.8%	19.1%
	35-44	27.6%	29.0%	42.5%	21.5%	22.7%
	45-56	27.6%	28.0%	22.5%	30.0%	28.2%
	55-64	13.6%	14.0%	7.5%	15.4%	15.5%
	65+	2.6%	2.0%	1.3%	3.1%	3.6%
Education	No formal qualifications	4.8%	7.0%	1.3%	6.9%	2.7%
	High school or lower	27.4%	31.0%	18.8%	26.2%	31.8%
	Bachelor's degree or equivalent	34.5%	27.0%	48.8%	30.8%	35.5%
	Master's degree or equivalent	25.5%	27.0%	27.5%	24.6%	23.6%
	Doctoral degree (PhD)	6.7%	8.0%	3.8%	8.5%	5.5%
	Other ⁷	1.2%	0.0%	0.0%	3.1%	0.9%
Association membership	Yes	77.6%	91.0%	15.0%	93.1%	92.7%
	No	22.4%	9.0%	85.0%	6.9%	7.3%
Financial position	Very good (room for investments)	14.5%	16.0%	5.0%	18.5%	15.5%
	Good (sufficient reserves)	28.1%	32.0%	27.5%	31.5%	20.9%
	Medium (profitable but with considerable debt)	33.8%	33.0%	32.5%	32.3%	37.3%
	Low (profitability varies, high indebtedness)	5.7%	3.0%	12.5%	3.1%	6.4%
	Bad (structurally loss-making)	3.8%	4.0%	1.3%	3.1%	6.4%
	I don't want to answer	14.0%	12.0%	21.3%	11.5%	13.6%

⁷ Respondents who selected "Other" provided the following answers (translated into English):
(IT): agronomist, nursery technician; (RO): orchard owner, commercial director, vegetable grower, owner of a plant protection store, fruit tree orchard manager, engineer, researcher, horticultural engineer; (DE): co-owner; (FR): both [owner and manager], production manager, sector manager.

5.2 Nursery characteristics

The majority of the respondents were the nursery owners (81%), with a smaller share of general managers (15%) (

Table 3). Most nurseries had been operating for more than ten years (56%), and only 13% had been founded within the past three years.

In terms of size, nurseries were typically small to medium holdings. About 59% operated on areas between 2 and 10 hectares, while 11% on less than 2 hectares and 5% on more than 20 hectares. Similarly, in terms of the number of employees, 43% of nurseries are categorized as small-sized enterprises (10-49 employees), 33% as medium-sized (50-249 employees), and 18% as micro-enterprises (<10 employees). Large enterprises with over 250 employees accounted for 6% of the sample.

Table 3. Operational characteristics (nursery-focused) in the survey sample.

		Total	Italy	Romania	Germany	France
Role	I am the owner	81.4%	79.0%	87.5%	80.8%	80.0%
	I am the general manager	15.2%	19.0%	2.5%	18.5%	17.3%
	Other	3.3%	2.0%	10.0%	0.8%	2.7%
Years in operation	Less than 3 years	12.6%	11.0%	21.3%	9.2%	11.8%
	3-10 years	31.4%	26.0%	50.0%	26.2%	29.1%
	11-20 years	31.7%	32.0%	17.5%	37.7%	34.5%
	More than 20 years	24.3%	31.0%	11.3%	26.9%	24.5%
Nursery size (unit area)	Less than 2 ha	11.4%	7.0%	26.3%	5.4%	11.8%
	From 2 to 4.9 ha	28.6%	31.0%	23.8%	31.5%	26.4%
	From 5 to 9.9 ha	30.7%	27.0%	28.8%	33.1%	32.7%
	From 10 to 19.9 ha	24.3%	27.0%	13.8%	26.9%	26.4%
	More than 20 ha	5.0%	8.0%	7.5%	3.1%	2.7%
Nursery size (number of employees) ⁸	Micro-sized enterprise (0-9 employees)	17.6%	11.0%	37.5%	16.9%	10.0%
	Small-sized enterprise (10-49 employees)	42.9%	35.0%	42.5%	43.8%	49.1%
	Medium-sized enterprise (50-249 employees)	33.1%	46.0%	16.3%	32.3%	34.5%
	Large-sized enterprise (250+ employees)	6.4%	8.0%	3.8%	6.9%	6.4%

Nurseries in the sample were highly diversified in terms of plant material produced or sold (**Figure 2**). Ornamental plants dominated across all surveyed countries, produced or sold by roughly 80% of nurseries in the total sample, and by more than 90% in Italy, Germany, and France. Fruit trees were also widely represented (63% overall), particularly in Italy (73%) and France (70%). Vegetables and herbs accounted for 39% of nurseries, with only a small variation across Member States (34.6% in Germany to 43.8% in Romania). Production of forestry species and grapevines was less common (12% of the total sample, in both cases). A small fraction (4%) indicated “other” plant types, most notably in Romania (16%).

⁸ Classifications follow the European Commission [definition of SMEs](#), which distinguishes micro, small, and medium-sized enterprises based on the number of employees and either annual turnover or balance sheet total.

Q: What type of plants do you primarily produce or sell at your nursery?
(select all that apply)⁹

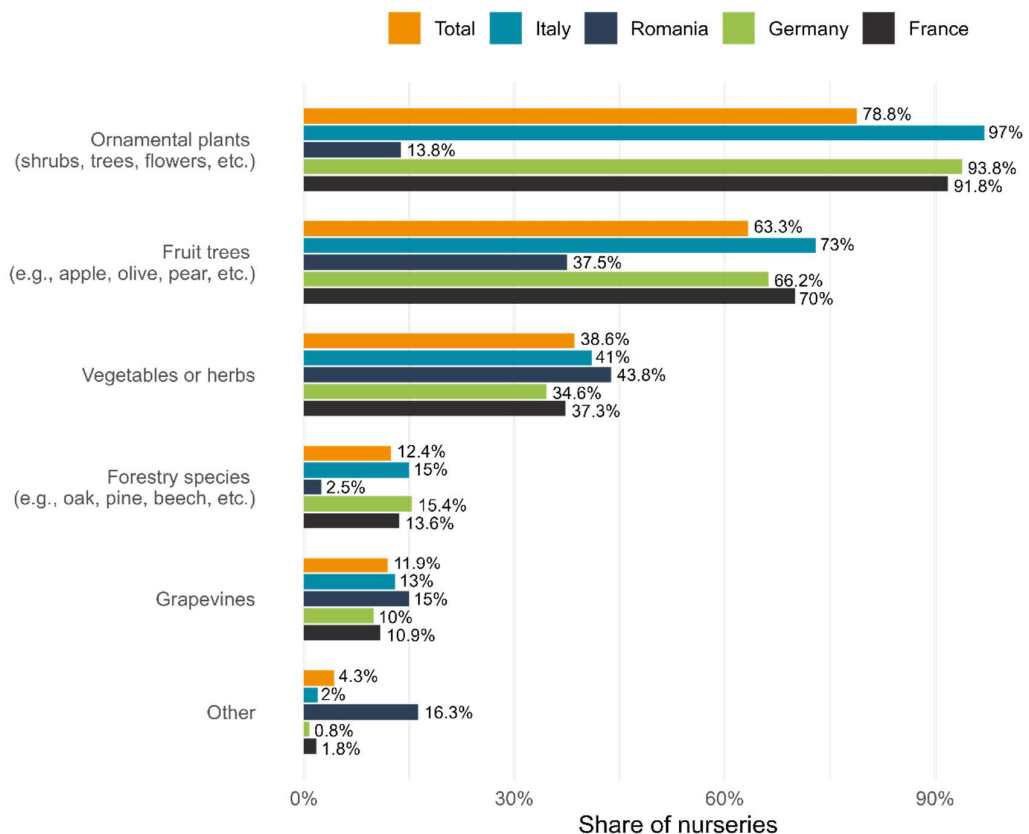


Figure 2. Type of plants cultivated or sold by surveyed nurseries.

Most nurseries reported trading frequently within the EU (60.7%, overall), with particularly high shares in Italy (75%), followed by Germany and France (65%, in both MSs) (**Figure 3**). Moreover, frequent exports outside the EU were noted by half of the sample, reaching over 60% in Italy, Germany, and France, while being rare in Romania (0%). Interestingly, 45% of Romanian nurseries indicated no trading activity.

⁹ Respondents who selected “Other” provided the following answers (translated into English):
(IT): flowering plants, shrubs; (RO): cherry, sour cherry, mushrooms, maize, strawberries, raspberries, blackberries, alfalfa, sunflower, apple, pear, plum, cherry, fruit shrubs, “we do not commercialize”, watermelon, melon, cereals (wheat, rapeseed, maize, barley), blueberries; (DE): perennial grasses and aquatic plants; (FR): shrubs, vegetable and flowering plants.

Q: Do you export/sell plants or plant products? (select all that apply)

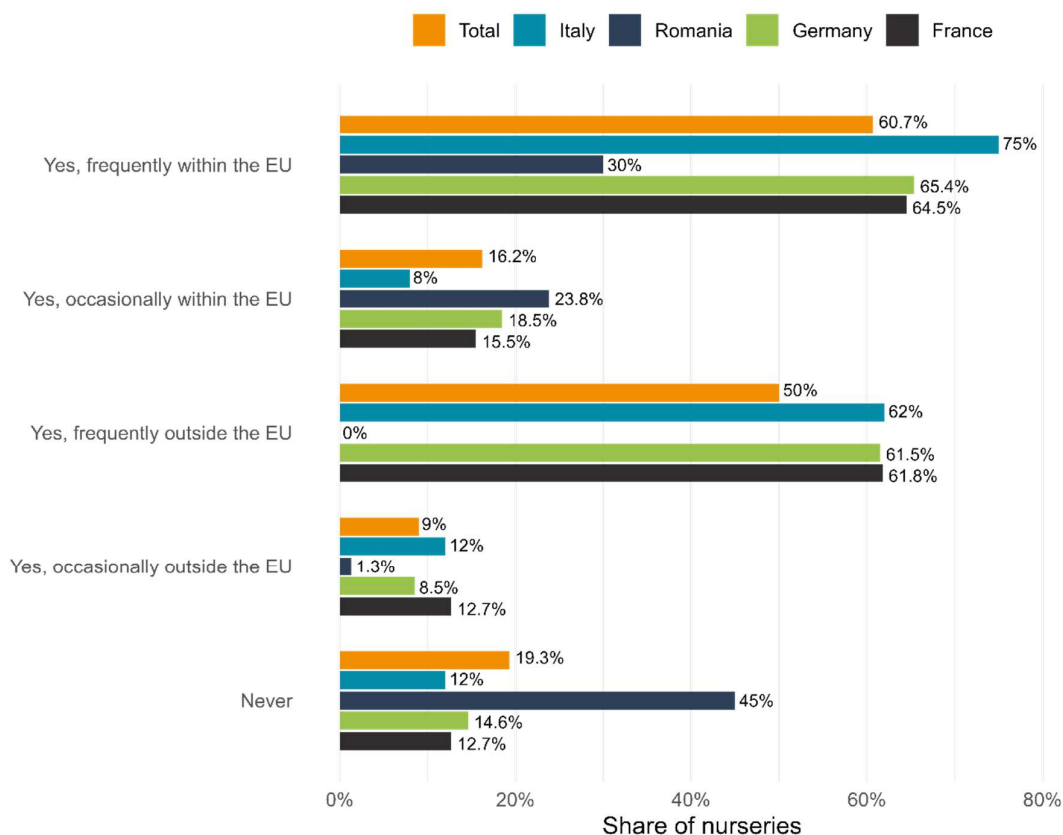


Figure 3. Nursery involvement in plant trade.

5.3 Current practices and experience

Across the total sample, 77.4% of nurseries reported having experienced problems related to invasive pests or pathogens. This share was markedly high in Italy (89%), France (87%), and Germany (81.5%), whereas in Romania, only 42.5% of nurseries reported such experience (Figure 4).

Q: Has your nursery ever experienced problems related to invasive pests or pathogens?

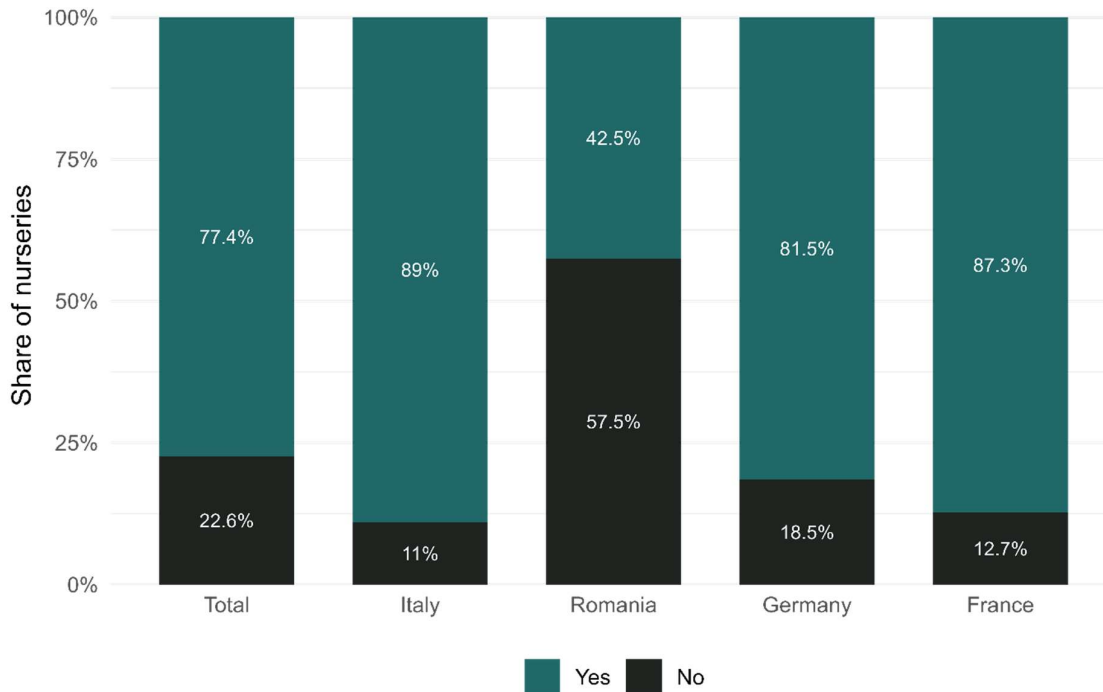


Figure 4. Experience with invasive pest/pathogen among surveyed nurseries.

Respondents who selected “Yes” were asked to specify the pests or pathogens they had encountered. Across countries, fungal diseases were most frequently mentioned. In Italy, common examples included downy mildew (*Peronospora*), grey mold (*Botrytis*), leaf spots (*macchie fogliari*), rusts (*ruggine*), and wilts (*Fusarium*). Viral infections (*ppv virus*), bacterial cankers (*Xylella fastidiosa*), and insect pests such as aphids (*afidi*), mites (*ragnetto rosso*), whiteflies (*mosche bianche*), thrips (*tripidi*), as well as invasive alien species such as *Popillia japonica* and *Halyomorpha halys* (*cimice asiatica*).

In Romania, respondents similarly highlighted fungal diseases (e.g., *fuzarioza*, *Verticillium*, *Botryosphaeria*, *Phomopsis*, moniliosis), downy mildew (*Bremia lactucae*), powdery mildew (*făinare*), leaf spots (*pătarea frunzelor*), as well as bacterial infections such as *Xanthomonas campestris*, fire blight (*Focul bacterian*), and collar canker (*Cancerul coletului*). Insects and mites mentioned included aphids (*afide*), thrips (*tripsi*), red spider mite (*păianjenul roșu*), tomato leafminer (*tuta absoluta*), whiteflies (*musculița albă*), codling moths (*viermele mărului*), and tanymecus (*tanimecus*). Other mentions included snails (*melci*) and unknown pests (*dăunători necunoscuți*).

In Germany, fungal diseases dominated– downy mildew (*Falscher Mehltau*), powdery mildew (*Echter Mehltau*), grey mold (*Grauschimmel*, *Botrytis*), *Septoria*, leaf spots (*Schwarzfleckigkeit*), late blight (*Braunfäule*), *Cercospora*, wilts (*Verticillium*, *Fusarium*), and *Phytophthora ramorum* – with frequent references to aphids (*Blattläuse*), thrips (*Thripse*), mites (*Milben*), caterpillars (*Raupen*), and whiteflies (*Weißer Fliegen*). *Xylella fastidiosa* was also mentioned multiple times. In France, respondents most often reported fungal diseases – powdery mildew (*maladie blanche*), grey mold (*moisissure grise*), downy mildew (*mildiou*), leaf spots (*taches foliaires*),

Cercospora, anthracnose, and wilts (*Verticillium*, *Fusarium*), often noted simply as *fungi*, alongside aphids (*pucerons*), mites (*Acaries*), whiteflies (*aleurodes*), thrips, and, in general, larvae (*larves de papillons*). Other mentions included viruses (*virus*), nematodes (*nématodes*), and occasional notes of dwarfing symptoms (*nanisme*).

More than half of the nurseries in the total sample reported performing inspection on incoming consignments always or frequently, with small variation for Italy, Germany, and France (**Figure 5**). Responses from Romanian nurseries reflect that inspections are more frequent when the imported consignments are considered high-risk. Moreover, reliance and trust on pest-free certificates were also relatively large (36.7% overall). Only a small minority (2.4%) indicated not conducting phytosanitary inspections at all, with Romania standing out with 11.3%.

Q: Do you perform inspections on incoming plant consignments at your nursery?

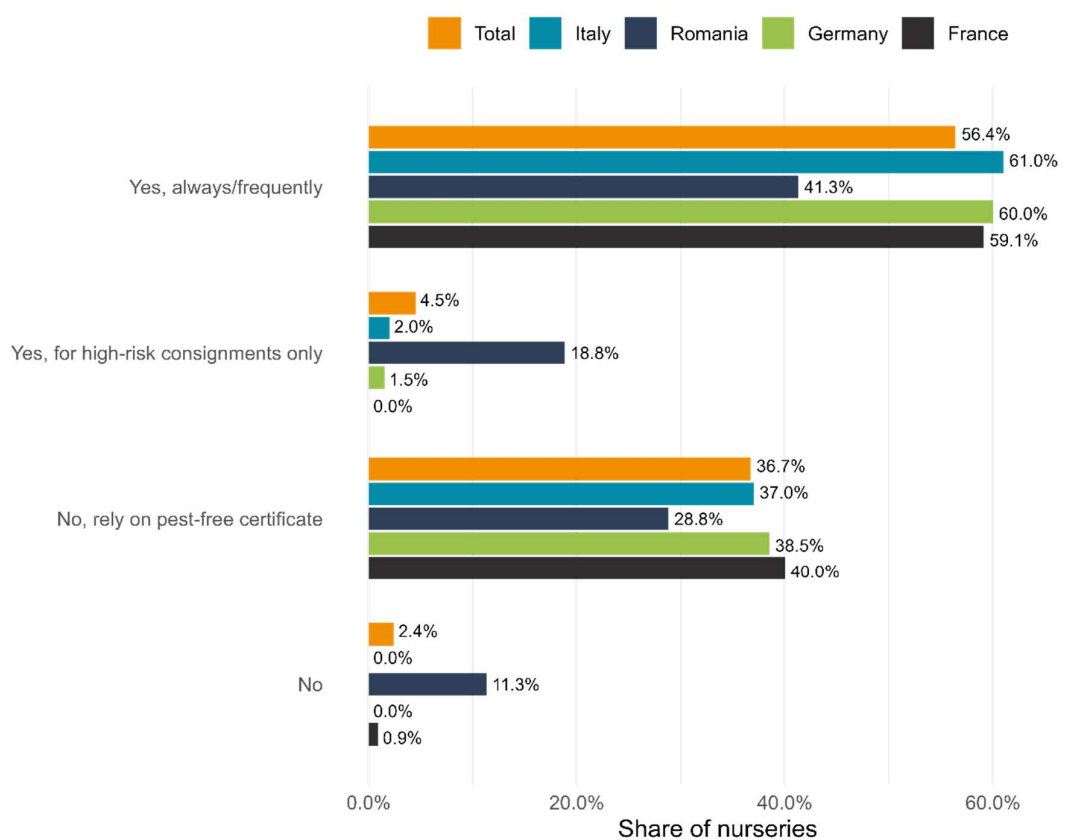


Figure 5. Inspection frequency for incoming plant consignments at surveyed nurseries.

Among nurseries conducting phytosanitary inspections, visual inspection by staff was almost universal (95.7%), reaching 100% in both Italy and France (**Table 4**). Laboratory diagnostics (outsourced) were also common (76.6%), especially in France (95.4%), Italy (93.7%), and Germany (90%), but were rarely used in Romania (6.3%). In-house diagnostics were less frequent (<10%), though somewhat higher in Romania (14.6%) and Germany (11.3%). Lastly, only a negligible proportion of the total sample reported using no specific inspection method (0.4%) or other approaches (1.6%).

Q: *If yes, what method(s) do you use to perform the inspection? (Select all that apply)*

Table 4. Methods used by surveyed nurseries to perform inspections on incoming plant consignments.

	Total	Italy	Romania	Germany	France
Visual inspection (nursery staff)	95.7%	100.0%	89.6%	92.5%	100.0%
Laboratory diagnostics (in-house)	9.8%	7.9%	14.6%	11.3%	6.2%
Laboratory diagnostics (outsourced)	76.6%	93.7%	6.3%	90.0%	95.4%
No specific method	0.4%	0.0%	2.1%	0.0%	0.0%
Other ¹⁰	1.6%	0.0%	4.2%	2.5%	0.0%

5.4 Opinions and attitudes

This subsection presents respondents' opinions and attitudes toward pest detection and regulatory measures (**Figure 6-10**), their perceptions of responsibility and trust across different actors (**Figure 11-15, Table 5**), and their perceived barriers to adopting a VOC sensor (open-ended responses by country).

Across the total sample, respondents showed a strong agreement that ensuring incoming plant material is pest-free is the nursery's responsibility (83.3% agree/strongly agree) (**Figure 6**). Trust in plant health certificates was also high (76.8% agree/strongly agree). Furthermore, a considerable proportion of respondents agreed that the current regulatory phytosanitary measures are strict (65.4% agree/strongly agree) and that the regulatory scheme against invasive pests and pathogens affects their business (62.8% agree/strongly agree). 64% of the respondents believe that early pest detection is critical for the financial future of their business. Views on current protection against invasive pests and pathogens at the nursery level were mixed, as 53.9% agreed that they are well protected, 32.7% were neutral, and 13.4% disagreed. Regarding the VOC sensor, 34.6% expressed a positive attitude towards adopting it if available, 40.6% were neutral, and 24.6% disagreed. Likewise, 39.6% agreed that a VOC sensor could improve reputation and customer trust, while 37% of the responses were neutral and 23.4% negative.

¹⁰ Examples of "Other" responses were: (RO): phytosanitary inspection by the Ministry of Agriculture (*inspectie fitosanitara de la MADR*); (DE): external consultant (*Externer Berater*).

Q: For each of the questions below, select the response that best characterizes how you feel about the statement, where: 1= Strongly Disagree, 2= Disagree, 3= Neither Agree Nor Disagree, 4= Agree, 5= Strongly Agree.

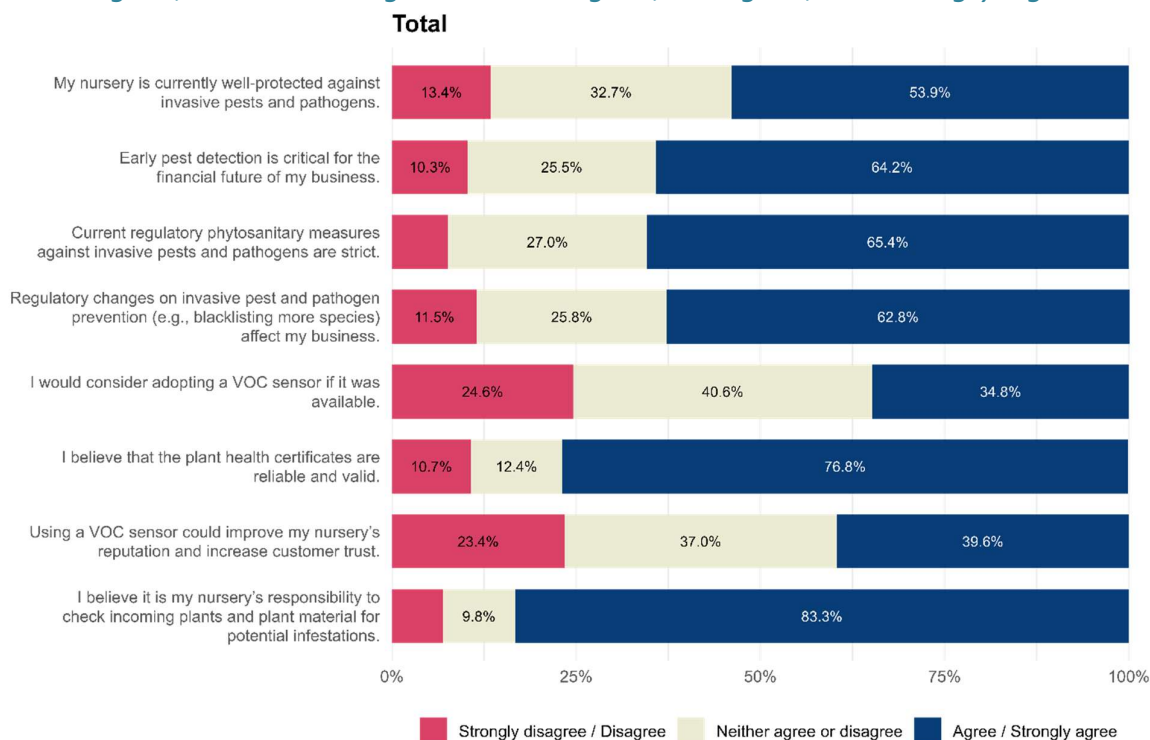


Figure 6. Opinions and attitudes of nursery operators in the total sample.

At the country level, responses revealed heterogeneous attitudes. In Italy, the strongest consensus was on responsibility, with 88% of respondents agreeing that nurseries should check incoming plant consignments, alongside high levels of agreement that plant health certificates are valid (79%) and that regulatory changes affect their business (74%) (**Figure 7**). Further, almost one-third expressed willingness to adopt a VOC sensor. In Romania, the majority considered early pest detection critical for the financial future (85.1%), while less than half (46.4%) believed that regulatory changes on invasive pest and pathogen prevention affect their businesses (**Figure 8**). In Germany, 81.5% agreed on nursery responsibility, and nearly one-third expressed willingness to adopt a VOC sensor (29.3%) or considered that adopting a VOC sensor would improve the nursery's reputation and customer trust (29.2%) (**Figure 9**). However, neutrality was the dominant position on both statements (42.3% and 40.8%, respectively). In France, results were comparable to Germany, with confidence in phytosanitary certificates (83%), while willingness to adopt a VOC sensor was somewhat higher than in Germany (**Figure 10**).

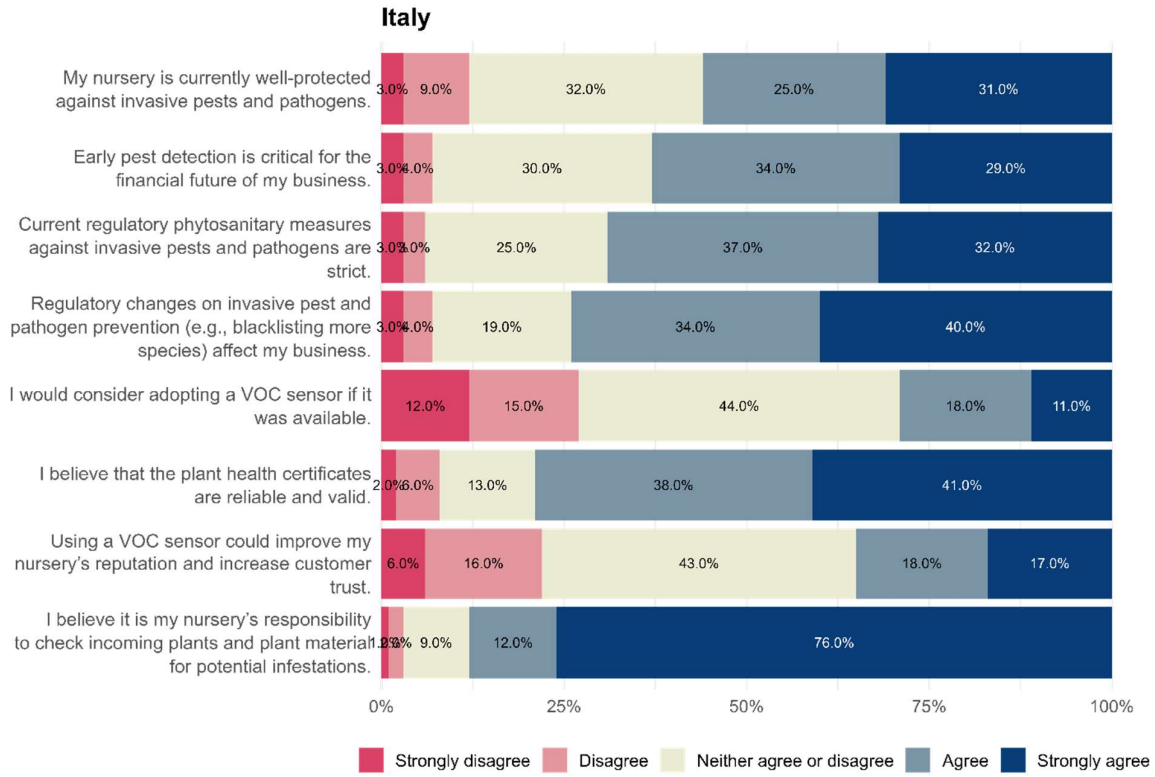


Figure 7. Opinions and attitudes of nursery operators in Italy.

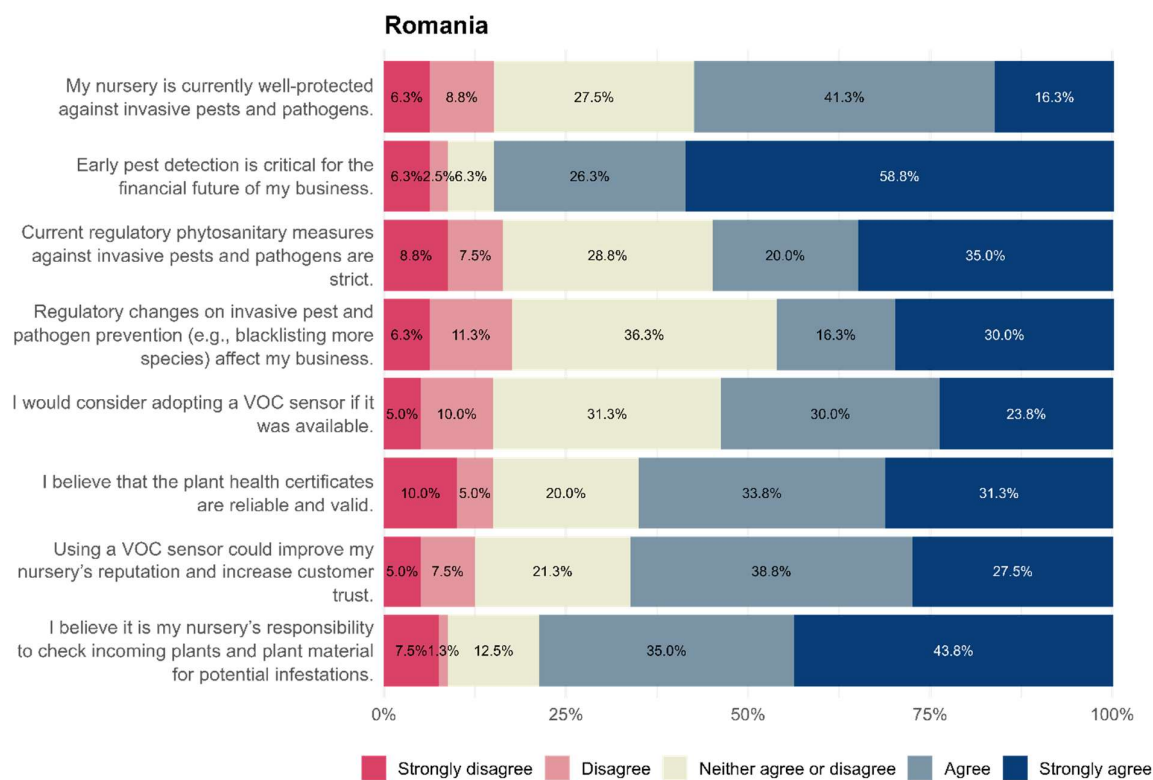


Figure 8. Opinions and attitudes of nursery operators in Romania.

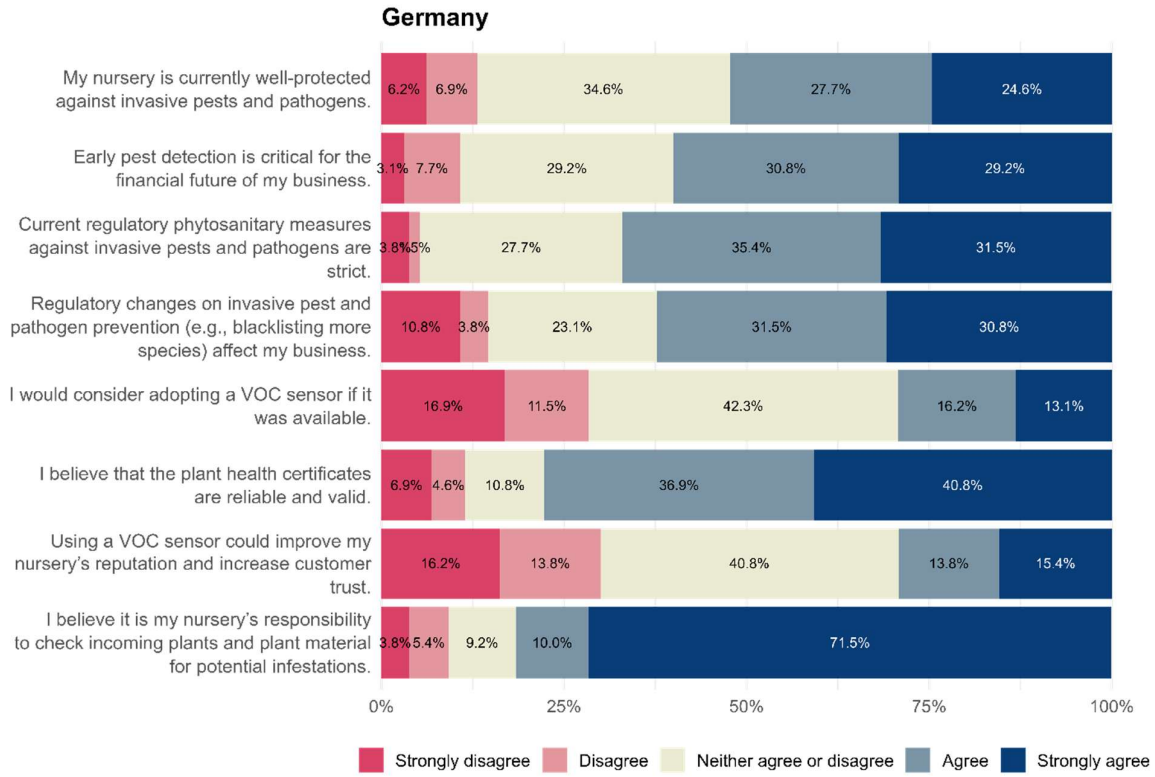


Figure 9. Opinions and attitudes of nursery operators in Germany.

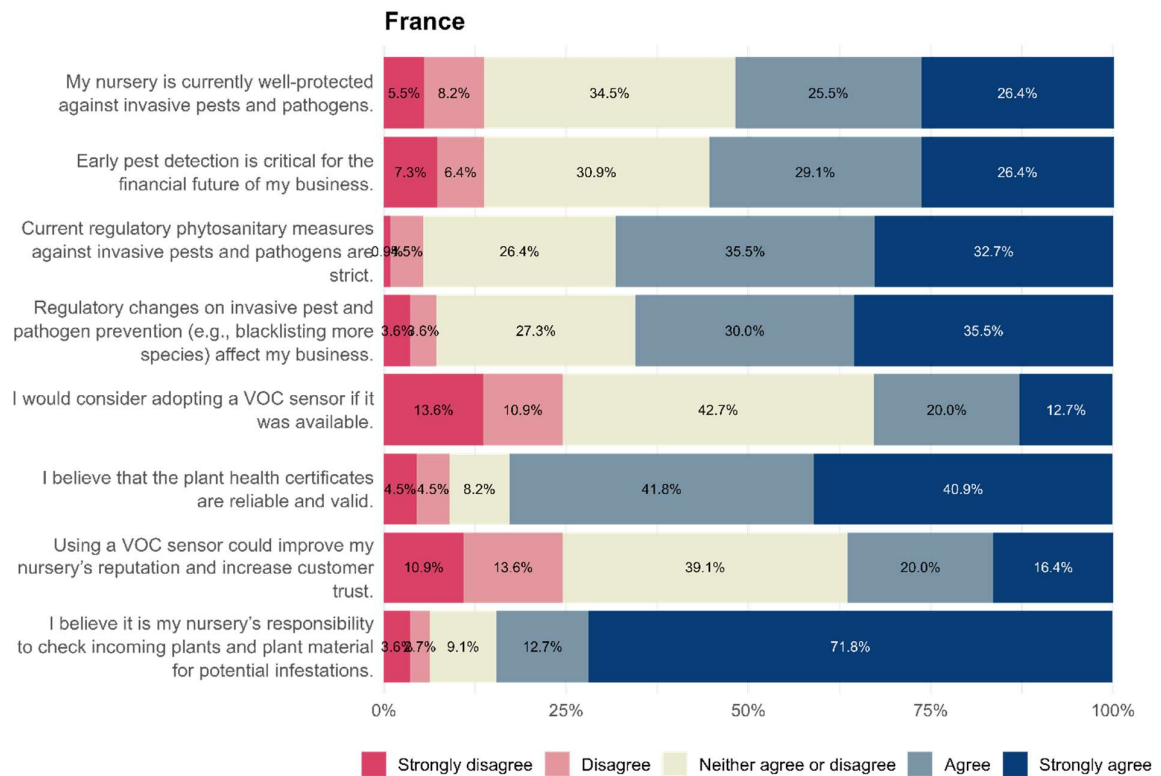


Figure 10. Opinions and attitudes of nursery operators in France.

Perceptions of responsibility and trust varied across different actors and countries. In the total sample, a clear majority assigned responsibility for pest detection to national plant protection organizations (NPPOs, 89%), exporters (88%), nurseries (86%), border control facilities (81%), while only 32% considered farmers responsible (**Figure 11**). Trust levels for pest and pathogen detection were highest for exporters, with 79% assigning scores of 4 and 5, followed by NPPOs (76%) and border control/customs (74%). In contrast, over half expressed trust in nurseries (52%), while trust in farmers was limited, with 56% of the respondents selecting the neutral midpoint.

Q: *In your opinion, thinking about the current situation, how responsible is each of the following actors for ensuring that plants and plant material are free from pests and pathogens? For each actor, please indicate whether you believe they have responsibility for pest detection, and how much you trust them to perform this role effectively (1 = very low trust, 5 = very high trust).*

Total

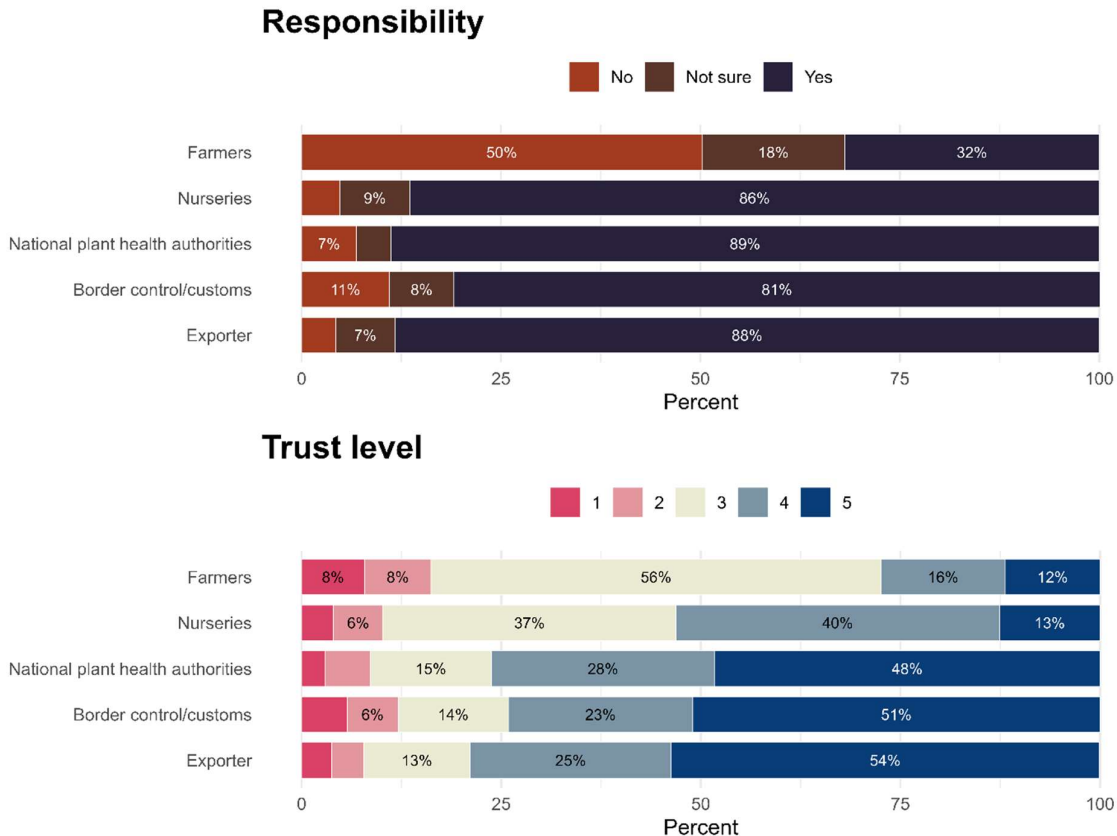


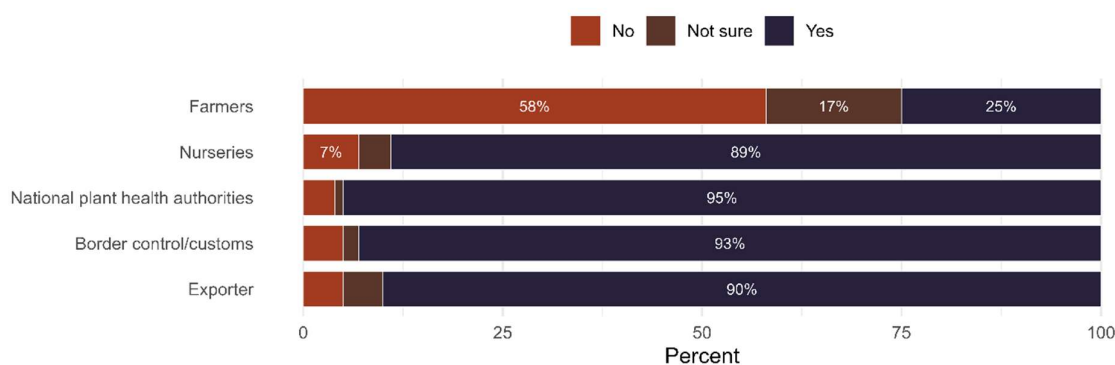
Figure 11. Perceptions of responsibility and trust in different actors (farmers, nurseries, national plant health authorities, border control/customs, and exporters) for ensuring that plants and plant products are free from pests and pathogens, across the total sample.

In Italy, the responsibility for pest-free plant material was heavily attributed to NPPOs (95%), border control points (93%), exporters (90%), and nurseries (89%) (**Figure 12**). Trust levels were particularly high for those actors as well (>80%), except for the somewhat lower case of nurseries (46.5%). Farmers were again not perceived as the ones who should be responsible. In Romania, responsibility was more evenly distributed compared to Italy, Germany, and France, and notably lower for border control (46%) and exporters (72%) (**Figure 13**). Similarly, trust levels were less concentrated at the 4-5 scores. For instance, only 47% expressed trust in border control facilities, while farmers (59%) and nurseries (72%) received comparatively higher trust than in the other surveyed MSs. In Germany, respondents attributed responsibility broadly, with >86% in all actors except farmers (36%) (**Figure 14**). Trust was highest in border control (81%), NPPOs (80%), and exporters (80%), while a big proportion of respondents remained neutral (64%). In France, responsibility attribution closely resembled Italy and Germany, with all actors rated as primarily responsible (>87% in all cases), apart from farmers, who were less often

selected (21%) (**Figure 15**). Trust was strongest in exporters (88%), followed by border control agencies (81%), and NPPOs (79%), while trust in nurseries and farmers was lower, with 46% and 58% choosing the neutral stance.

Italy

Responsibility



Trust level

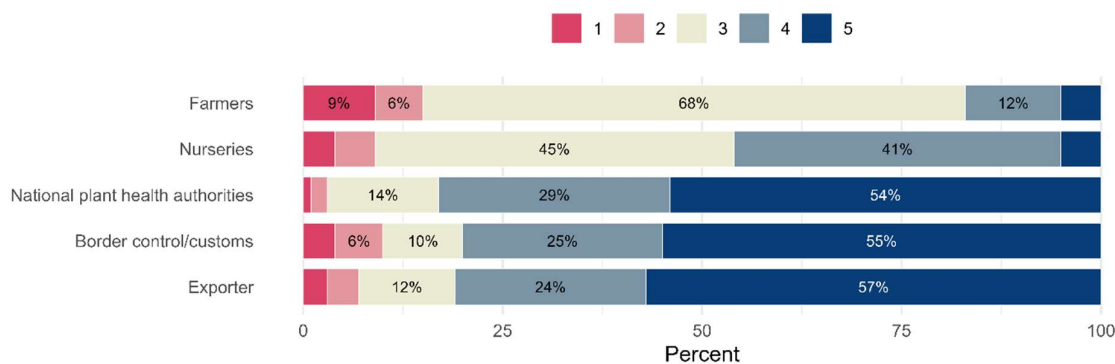
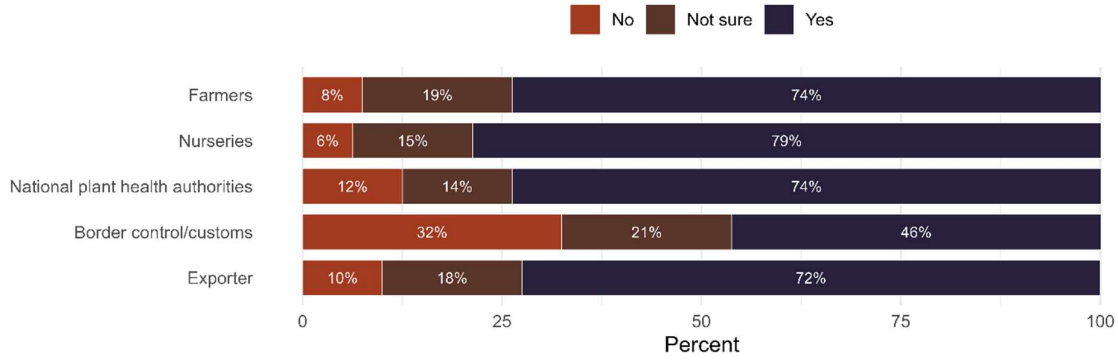


Figure 12. Perceptions of responsibility and trust in different actors (farmers, nurseries, national plant health authorities, border control/customs, and exporters) for ensuring that plants and plant products are free from pests and pathogens, in Italy.

Romania

Responsibility



Trust level

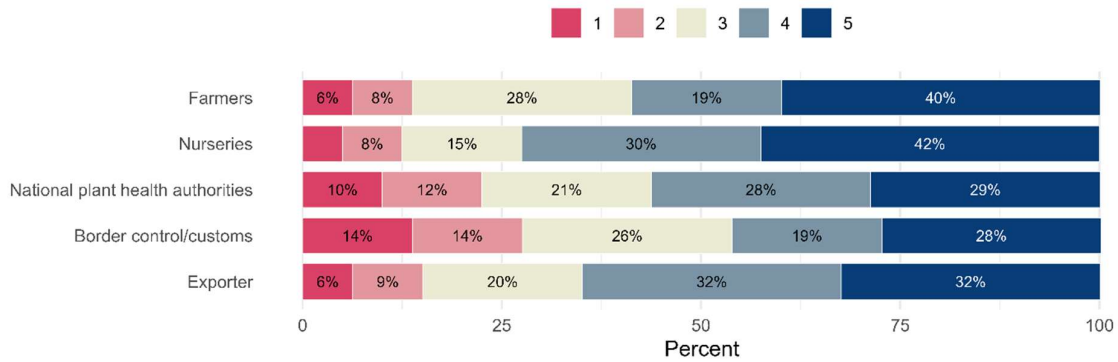
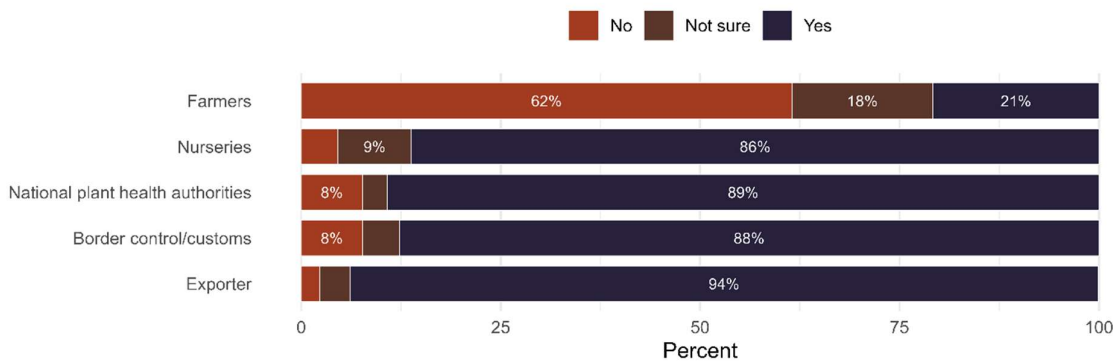


Figure 13. Perceptions of responsibility and trust in different actors (farmers, nurseries, national plant health authorities, border control/customs, and exporters) for ensuring that plants and plant products are free from pests and pathogens, in Romania.

Germany

Responsibility



Trust level

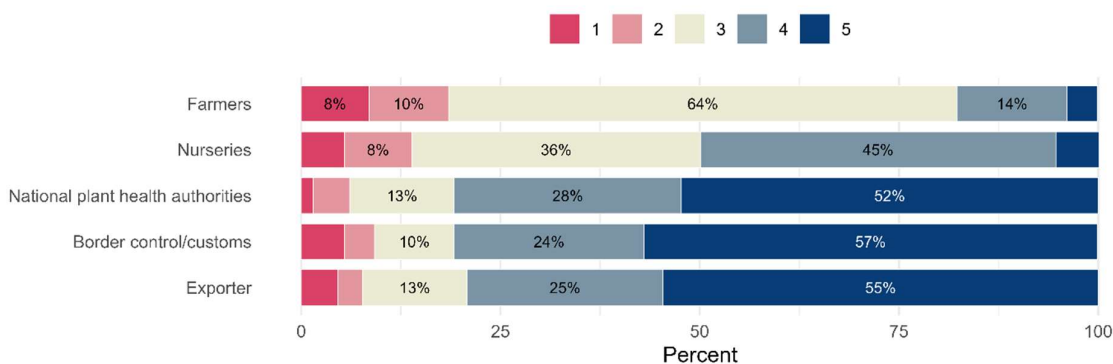
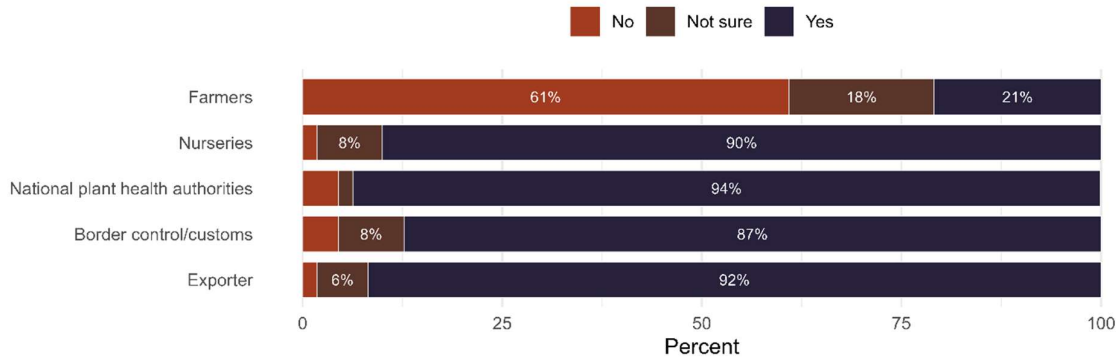


Figure 14. Perceptions of responsibility and trust in different actors (farmers, nurseries, national plant health authorities, border control/customs, and exporters) for ensuring that plants and plant products are free from pests and pathogens, in Germany.

France

Responsibility



Trust level

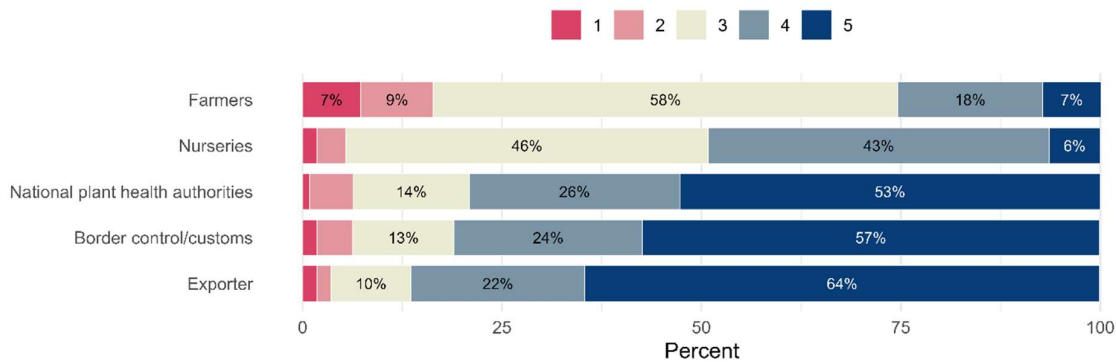


Figure 15. Perceptions of responsibility and trust in different actors (farmers, nurseries, national plant health authorities, border control/customs, and exporters) for ensuring that plants and plant products are free from pests and pathogens, in France.

When asked where responsibility for pest and pathogen prevention/detection should lie in the future, respondents most frequently selected exporters (76.1%), NPPOs (75.9%), and border control agencies (67.3%) (**Table 5**). Fewer respondents placed responsibility on nurseries (36.8%) or farmers (22%). Zooming in on country-level responses, we observe similar beliefs in Italy, Germany, and France, where the majority emphasize exporters (82-84%), NPPOs (80-82%), and border control points (74-81%) as the main actors responsible; relatively few pointed to nurseries (30-34%) and even less to farmers (9-16%). The picture differed in Romania, as farmers bore the highest future responsibility (64%), followed by nurseries (57.5%), while few respondents selected border control agencies (25%).

Q: *In your opinion, where should most of the responsibility for pest and pathogen prevention lie in the future? (select all that apply)*

Table 5. Views of surveyed nurseries on where the main responsibility for pest and pathogen prevention should lie in the future.

	Total	Italy	Romania	Germany	France
Farmers	22.0%	16.2%	63.8%	11.5%	9.1%
Nurseries	36.8%	31.3%	57.5%	33.8%	30.0%
National plant health authorities	75.9%	79.8%	55.0%	82.3%	80.0%
Border control/customs	67.3%	80.8%	25.0%	73.8%	78.2%
Exporter	76.1%	83.8%	47.5%	82.3%	82.7%
Other	1.4%	0.0%	0.0%	0.0%	5.5%

Q: *Is there anything that would discourage you from adopting a new detection method, even if it were accurate and fast?*

Across all countries, the most frequently mentioned barrier to adopting a VOC sensor, even if accurate and fast, was the high cost of the technology, including the purchase price, maintenance, and, in some cases, additional training support. In Italy, respondents emphasized financial constraints and uncertainty about recovering the investment, with several describing the VOC sensor as a risky expenditure. Concerns also extended to the complexity of integration, staff training, and doubts about compatibility with the existing workflow, while some expressed satisfaction with current inspection methods. Similarly, in Romania, references to cost dominated, though some respondents stated they would face no barriers, given that the VOC sensor is efficient and reasonably priced. German nurseries again stressed financial concerns, particularly in light of rising input costs, and underlined additional concerns over the time and complexity of adapting to such technology, and potentially the need to train staff or seek external technical support. French respondents echoed these cost-related concerns, often noting that the small size of their nurseries made such investments prohibitive without government incentives. They also stressed risks associated with adaptation to the novel technology and expressed strong preferences for the standard existing inspection methods. A minority in all MSs indicated willingness to adopt the sensor if it is reliable, cost-effective, and accompanied by external support. The prevailing sentiment across the surveyed MSs was caution, primarily driven by financial and operational concerns.

5.5 Factors affecting VOC sensor adoption

This subsection is based on the sample derived from the follow-up survey ($n' = 343$). Across all four surveyed countries, the cost per inspection is consistently highly significant and negatively related to the likelihood of choosing a VOC-based detection technology. This indicates that higher costs discourage adoption and that nurseries are sensitive to the potential additional costs associated with integrating a VOC sensor into their existing workflows and inspection routines. The time needed to obtain inspection results is negatively related to adoption in Italy, Romania, and France. In these countries, longer waiting times reduce the appeal of the VOC sensor, implying that rapid feedback is an important aspect of the adoption potential of the device. On the other hand, in Germany, this relationship is not evident, as the coefficient of this attribute, although negative, is statistically insignificant. This means that inspection speeds do not show a meaningful influence with regard to the adoption decision of a VOC sensor in German nurseries.

Detection reliability is positively related to adoption in each country, implying that nurseries value accuracy when conducting phytosanitary inspections.

In Italy, Germany, and France, greater reliability makes the VOC sensor more attractive, underscoring the importance of diagnostic performance as a driver of adoption.

Notably, detection reliability is insignificant in Romania, suggesting that this attribute may not play a role in the decision-making process.

Table 6 shows the results of the mixed logit model to explain which factors affect respondents' decisions to adopt a VOC-based sensor for the detection of pests and pathogens in each country. Across all four surveyed countries, the cost per inspection is consistently highly significant and negatively related to the likelihood of choosing a VOC-based detection technology. This indicates that higher costs discourage adoption and that nurseries are sensitive to the potential additional costs associated with integrating a VOC sensor into their existing workflows and inspection routines.

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Notably, detection reliability is insignificant in Romania, suggesting that this attribute may not play a role in the decision-making process.

Table 6. Mixed logit estimation results to explain the adoption potential of VOC-based detection technology by European nurseries.

	Italy	Romania	Germany	France
	Coefficients			
Time to receive results	-0.298***	-0.204**	-0.007	-0.187***
Detection reliability	0.022***	0.016	0.024***	0.009**
Cost per inspection	-0.134***	-0.117***	-0.104***	-0.096***
Certification potential	0.148	0.641**	-0.342***	0.241***
Ownership (Purchased)	-0.194	0.237	-0.164	-0.041
Ownership (Co-owned)	0.025	-0.271	0.095	0.111
ASC (alternative-specific constant)	0.403	1.958*	-0.800*	0.797*
	Standard deviations			
Time to receive results	-0.011	0.287**	-0.000	0.140**
Detection reliability	0.004	0.037***	0.000	0.000
Cost per inspection	0.069***	0.068	-0.000	0.032
Certification potential	0.005	1.618***	0.368**	0.004
Ownership (Purchased)	-0.003	0.111	0.001	0.001
Ownership (Co-owned)	-0.004	-0.736**	-0.009	-0.000
ASC	0.020	6.508***	-0.204	-0.007

The model was estimated using StataNow/BE 18.5. *, **, and *** denote significance at the 0.10, 0.05, and 0.01 level, respectively. The mixed logit models are based on calculations with 1000 Halton draws.

The relationship between certification potential and adoption varies across the surveyed Member States. In Romania and France, the option for nurseries to certify their plant consignments as inspected and pest-free is positively related to adoption, indicating a higher perceived added value of the VOC sensor, potentially via compliance assurance or stronger customer trust, and higher business reputation. Conversely, in Germany, certification potential is negatively related to adoption, suggesting that German nurseries may perceive this certification scheme as an additional responsibility and administrative burden. In Italy, there is no clear relationship between certification potential and decision-making towards the adoption of a VOC sensor, as the coefficient is not significant.

Our results suggest no strong relationship between adoption and the two ownership modes of the technology (purchased or co-owned, relative to outsourced). This implies that nurseries' attitudes do not shift between ownership structures when evaluating the VOC sensor. Lastly, the ASC captures the overall inclination to adopt a VOC sensor configuration or choose the status quo (existing inspection methods) over it. Positive ASC values that are statistically significant in Romania and France show a positive attitude toward VOC sensor adoption, whereas in Germany, the negative sign highlights a preference for the status quo.

Table 7 provides the WTP estimates for each attribute included in the DCE by country. Across the countries where the time to receive results plays a role, nurseries are willing to pay between €1.72 and €2.22 per hour reduction in inspection time. In Germany, where time does not affect choices, no WTP value is computed.

Similarly, detection reliability shows consistently positive WTP values across all countries besides Romania. Nurseries are willing to pay for improvements in accuracy, with values ranging from €0.10 per percentage point in France to €0.23 per percentage point in Germany. This indicates that reliability is an important attribute of such a detection device.

Table 7. Willingness to pay (WTP) estimates from the mixed logit model(s). WTP values are reported only for statistically significant attributes. Confidence intervals are shown in brackets (5%; 95%).

	Italy	Romania	Germany	France
Time to receive results (€/hour)	-2.22 (-3.31; -1.47)	-1.74 (-4.18; -0.35)	-	-1.93 (-3.32; -1.03)
Detection reliability (€/%)	0.17 (0.09; 0.28)	-	0.23 (0.14; 0.36)	0.10 (0.00; 0.22)
Certification potential	-	5.47 (0.96; 14.60)	-3.26 (-5.82; -1.37)	2.50 (0.72; 5.03)
Ownership (Purchased)	-	-	-	-
Ownership (Co-owned)	-	-	-	-

Based on our findings, WTP estimates vary substantially for the certification potential attribute. Nurseries in Romania exhibit high WTP (€5.47) for the ability to certify their plant consignments as further inspected and pest-free, suggesting that this feature may enhance credibility and customers' trust. French nurseries also show a positive WTP for this attribute, though more moderate in magnitude (€2.50). In contrast, German nurseries exhibit a negative

WTP, indicating that the potential additional administrative implications of such a certification system may not justify the added value of the VOC sensor.¹¹

¹¹ Socio-demographic variables were also considered in the analysis; the ASC was interacted with selected socio-demographic characteristics in additional model specifications beyond the scope of this deliverable. **For the pooled sample, the results indicate that gender does not have a statistically significant effect on the likelihood of choosing a VOC sensor alternative.**

6 CONCLUSIONS

This deliverable provides an overview of current phytosanitary practices, attitudes, and barriers to adopting a novel VOC-based detection technology among nurseries in Italy, Romania, Germany, and France. The results show that nurseries acknowledge their role in ensuring pest-free plant material and rely primarily on visual inspections for incoming consignments. In Italy, Germany, and France, outsourced laboratory diagnostics are commonly used when needed, whereas in Romania, inspections rely almost exclusively on visual assessments. Experiences with invasive pests and pathogens are common, and early detection is broadly recognized as essential for business resilience and survival.

Respondents place primary responsibility for preventing the spread of pests and ensuring pest-free plant material on exporters, NPPOs, and border control agencies, while trust in the existing plant health certification systems (e.g., plant passport, phytosanitary certificate) remains high. At the same time, our findings indicate that nurseries operate in a context of regulatory heterogeneity and uncertainty, where responsibility for phytosanitary assurance increasingly shifts toward post-border actors. This reinforces the relevance of detection tools that can be used at the nursery level to complement, rather than replace, existing inspection methods.

Interest in VOC-sensors is present but cautious; many respondents perceive the technology as expensive and are uncertain about the return on investment and its added value. Additional concerns include integration into existing workflows, staff training requirements, and operational complexity. The DCE results show that nurseries consistently prefer VOC sensors that are reliable, rapid, and affordable, while ownership structure plays a limited role in decision-making. Preferences regarding certification potential differ across the surveyed countries.

Overall, our results suggest that the successful adoption of VOC-based sensor technologies for pest and pathogen detection will depend not only on their technical performance but also on their economic feasibility. From a policy perspective, this could mean incentives and integration/harmonization into existing certification and inspection frameworks.

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8 APPENDIX

8.1 Survey instrument (English version)

Welcome

Thank you for participating in this survey by [Wageningen University & Research](#). This study is part of the “**PurPest**” project, which aims to improve the detection and management of invasive pests and pathogens across Europe.

Invasive pests and pathogens can cause serious economic and environmental damage in plant production systems. We aim to understand current detection practices and preferences for new technologies. This study focuses on a **Volatile Organic Compound (VOC) sensor**, which functions like an "electronic nose" and could help detect infested plants more rapidly and reliably. **Your views** are very important to us; they will contribute to understanding nursery-level needs and priorities and **help shape future EU plant health policies**. Our survey takes **15-20 minutes** to complete, participation is voluntary, and you remain **anonymous**.

Thank you,
Stelios Kartakis & the PurPest Research Team
stelios.kartakis@wur.nl

Data Protection

Your responses will be kept **confidential** and used only for research purposes by researchers of Wageningen University and Research (WUR) involved in this research. Data collected will be securely stored, anonymized, and reported only as aggregated results.

The survey consists of questions about your nursery, background information (e.g., age group, gender, level of education,...), and a Discrete Choice Experiment to learn about your preferences for new technologies. **Names, addresses, and other features allowing your identification are not collected**. You can withdraw and discontinue the survey at any time without consequences.

The study has been approved by the **WUR – Research Ethics Committee for non-medical research** as meeting the *Netherlands Code of Ethics for research in the social and behavioral sciences involving human participants*, and the **Ethics Advisor of the PurPest project**.

If you have questions or concerns about the study, please **contact**:

- Stelios Kartakis, Wageningen University, stelios.kartakis@wur.nl

For any concerns about your legal rights as a participant, please contact:

- **PurPest Ethics Advisor** [Anna Bąkowska, anna.bakowska@uw.edu.pl]
- **Secretariat of the WUR Research Committee** [rec@wur.nl]

Would you like to participate?

By selecting "I Agree", you indicate that you have read and understood the information provided above and voluntarily agree to participate in this study.

- I agree
 I do not agree

Section A: Your nursery

- A1. Which one of the following best describes your role in your business? (*select one*)
- I am the owner
 - I am the general manager
 - Other: _____
- A2. How long has your nursery been in operation? (*select one*)
- Less than 3 years
 - 3-10 years
 - 11-20 years
 - More than 20 years
- A3. What is the approximate size of your nursery? (*select one*)
- Less than 2 ha
 - From 2 to 4.9 ha
 - From 5 to 9.9 ha
 - From 10 to 19.9 ha
 - More than 20 ha
- A4. Which one of the following best describes its current size in terms of the total number of full-time employees? (*select one*)
- Micro-sized enterprise (0-9 employees)
 - Small-sized enterprise (10-49 employees)
 - Medium-sized enterprise (50-249 employees)
 - Large-sized enterprise (>250 employees)
- A5. What type(s) of plants do you primarily produce or sell at the nursery? (*Select all that apply*)
- Ornamental plants (shrubs, trees, flowers, etc.)
 - Fruit trees (e.g., apple, olive, pear, etc.)
 - Forestry species (e.g., oak, pine, beech, etc.)
 - Grapevines
 - Vegetables or herbs
 - Other (please specify): _____
- A6. Do you export/sell plants or plant products? (*Select all that apply*)
- Yes, frequently within the EU
 - Yes, occasionally within the EU
 - Yes, frequently outside the EU
 - Yes, occasionally outside the EU
 - Never

Section B: Pest and pathogen detection methods












The PurPest project explores new technologies, such as a VOC (*Volatile Organic Compound*) sensor, enabling the user to rapidly detect infested plants and plant material in a non-invasive manner. The VOC sensor works as an “electronic nose” by detecting gases emitted by plants that are infested with pests or pathogens.

Currently, most inspections are carried out at import control points. However, early infestations may go undetected, and intra-EU plant consignments are rarely re-inspected. Having a reliable in-house detection tool could help the European nursery sector reduce risks and avoid costly consequences if a quarantine pest or pathogen is discovered after delivery.








Example of a VOC sensor for pest and pathogen detection.

The following hypothetical options describe how a VOC sensor could be used to inspect incoming and outgoing plant consignments at your nursery. Each option presents a possible configuration of the VOC sensor (in terms of time to receive the inspection results, cost, ownership of the technology, certification potential, and detection reliability). The VOC sensor is expected to cost approximately €35.000 with a warranty period of two years and can be used for thousands of inspections over its lifespan, provided regular maintenance is performed. You may also choose to continue with your current practice (opt-out option) and decide against the usage of a sensor.

Attribute	Description	Levels	Symbol
Time to receive results	How long does it take to receive the inspection results	1 hour 2 hours 4 hours	  
Detection reliability	Likelihood that the VOC sensor correctly detects infested plants/plant material	70% 85% 95%	  
Cost per inspection	Costs to inspect one batch (regardless of size, regardless of ownership) ¹²	€2 €4 €6 €8 €10	     €2 €4 €6 €8 €10

¹² For the purposes of this survey, a “batch” can refer to any incoming plant consignment, such as a pallet or container.

Certification potential	Whether the nursery can certify that the plant consignment was further inspected and declared free from pests or pathogens	Yes No	 Yes  No
Ownership of the technology	How the nursery accesses the VOC sensor technology	Purchased (owned individually) Co-owned (e.g., with other nurseries) Outsourced (service provided by a contractor)	 Purchased  Co-owned  Outsourced

Note on “Cost per inspection”:

The “Cost per inspection” (€2-€10) is estimated assuming regular sensor use (e.g., 8 inspections/day, 5 days/week) over a 10-year life span. This estimate includes the sensor’s initial investment costs (€35.000) and annual maintenance costs (€1.000), but excludes labor costs. In the case of outsourced service provision, the same range reflected the fee paid per inspection (inclusive of operating costs, but excluding initial investment and maintenance).

Cheap talk to be shown before the first choice set:

Please consider each option carefully and choose the one that would best fit your nursery’s needs. There is no right or wrong choice. However, we ask you to answer as realistically as possible, as if these options were available to you.

>>Choice cards

When answering the previous choice tasks, did you intentionally ignore or not consider any of the following attributes? (*select all that apply*)

- Time to receive results
- Detection reliability
- Cost per inspection
- Certification potential
- Ownership of the technology
- Price of the VOC sensor
- I considered all attributes
- I am not sure

Section C: Current practices and experience

C1. Has your nursery ever experienced problems related to invasive pests or pathogens?

- Yes, with (plant or plant material affected, pest or pathogen): _____
- No

C2. Do you perform inspections on incoming plant consignments at your nursery? (*select one*)

- Yes, always or frequently
- Yes, but rather occasionally or for high-risk consignments only
- No, because we only buy from suppliers with a pest-free certificate (e.g., phytosanitary certificate, plant passport)
- No

C3. If yes, what method(s) do you use to perform the inspection? (*select all that apply*)

- Visual inspection (nursery staff)
 Laboratory diagnostics (in-house)
 Laboratory diagnostics (outsourced)
 No specific method
 Other (please specify): _____

Section D: Your opinion about detection methods

D1. For each of the questions below, select the response that best characterizes how you feel about the statement, where: 1= Strongly Disagree, 2= Disagree, 3= Neither Agree Nor Disagree, 4= Agree, 5= Strongly Agree.

	1	2	3	4	5
My nursery is currently well-protected against invasive pests and pathogens.					
Early pest detection is critical for the financial future of my business.					
Current regulatory phytosanitary measures against invasive pests and pathogens are strict.					
Regulatory changes on invasive pest and pathogen prevention (e.g., blacklisting more species) affect my business.					
I would consider adopting a VOC sensor if it was available.					
I believe that the plant health certificates are reliable and valid.					
Using a VOC sensor could improve my nursery's reputation and increase customer trust.					
I believe it is my nursery's responsibility to check incoming plants and plant material for potential infestations.					

D2. In your opinion, thinking about the current situation, how responsible is each of the following actors for ensuring that plants and plant material are free from pests and pathogens? For each actor, please indicate whether you believe they have responsibility for pest detection, and how much you trust them to perform this role effectively (1 = very low trust, 5 = very high trust)

Actor	Responsible?	Trust level (1-5)
Exporter	<input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> Not sure	<input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5
Border control/customs	<input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> Not sure	<input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5
National plant health authorities	<input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> Not sure	<input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5
Nurseries	<input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> Not sure	<input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5
Farmers	<input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> Not sure	<input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5

D3. In your opinion, where should most of the responsibility for pest and pathogen prevention lie in the future? (*select all that apply*)

- Exporter
 Border control
 National plant health authorities
 Nurseries
 Farmers
 Other: _____

D4. Is there anything that would discourage you from adopting a new detection method, even if it were accurate and fast? (open-ended)

Section E: Socio-demographic information

E1. Which of the following best describes your gender (*select one*)

- Female
- Male
- Other
- Prefer not to say

E2. What is the highest level of education you have completed? (*select one*)

- No formal qualifications
- High school or lower
- Bachelor's degree or equivalent
- Master's degree or equivalent
- Doctoral degree (PhD)
- Other: _____

E3. What is your age? (*select one*)

- 18-24
- 25-34
- 35-44
- 45-56
- 55-64
- 65+

E4. Are you or your nursery a member of any official association (e.g., European Nurserystock Association)?

- Yes
- No

E5. How do you assess the current financial position of your nursery business? (*select one*)

- Very good (room for investments)
- Good (sufficient reserves)
- Medium (profitable but with considerable debt)
- Low (profitability varies, high indebtedness)
- Bad (structurally loss-making)
- I don't want to answer

Would you like to leave a comment?

- Yes: _____
- No

Thank you very much for completing the survey!

End of the questionnaire

8.2 Identifying the coding error (shared with the subcontracted company)

Problem description

In July/August 2025, a Discrete Choice Experiment (DCE) was run across four countries (Romania, Italy, Germany, and France). The experiment was about nursery owners' willingness to use a Volatile Organic Compound (VOC) sensor to detect plant diseases.

The participants could always choose between Alternative 1, Alternative 2, and Alternative 3 (option out, no sensor usage). The alternatives 1 and 2 were classified by five attributes relevant to such a sensor (with example references):

- **Time** to receive the results of the analysis (Fragomeli et al., 2025)
- **Reliability** of the analysis results (Kragt & Llewellyn, 2014; Späti et al., 2022)
- **Cost** of the usage of a sensor (monetary attribute, constructed with PurPest project partners; reasoning is provided in the questionnaire)
- **Certification** – whether nurseries using these sensors can advertise this (increase in quality) (proposed for inclusion as an attribute by nurseries)
- **Ownership** – whether the expensive VOC sensor is purchased by the nursery, purchased by a group of nurseries (co-owned), or can be rented to perform inspection (outsourced) (Späti et al., 2022; Weissgerber & Hess, 2022)

These attributes and their levels were chosen in cooperation with nurseries and PurPest project partners, and their descriptions were double-checked for clarity. For attribute, attribute level, and design, we considered recent literature on the topic, such as Mariel et al. (2021). For further quality improvements, a cheap talk script was also included, highlighting that choices should reflect their real-world decision-making.

Nevertheless, the data analysis across all countries shows no results (no significant effects, varying signs; signs do not match expectations and vary by country). Furthermore, the estimated models show poor fit, with low pseudo- R^2 values (attribute-only models perform no better than null models).

In general, discrete choice experiments are often quite straightforward, which implies that wrong signs, especially for cost attributes, are strong indicators of data quality issues. A negative effect of higher costs is well described in the literature (and in line with behavioral economics), and therefore, one would always expect a correct sign of the cost attribute. When this is not the case and all attributes and their effects are random, data quality issues (especially data corruption) are very likely.

Considering the DCE literature, data corruption can refer to the mislabeling of the outcome (e.g., default or no-default) for some records (Stein, 2016). When data is corrupt, this results in low model quality, and quality indicators such as the log-likelihood and the pseudo- R^2 can hence be used to detect whether the issue lies in data corruption.

Stein (2016) further shows that mislabeling of 5 % of the data already affects models negatively, with powerful models being more strongly affected than less powerful ones.

Tests performed to check data quality

Cause	Description of performed checks	Evaluation
Mismatched data	<p>Checks: Comparison of model fits (null model and attribute only) and visual checks for high levels of randomness (evaluation of the excel table where the share of choices for each alternative are recorded), checking code</p> <p>Results: There is no explanatory power in attribute only models, data appears random, for some choice sets almost equal distributions between the first and second alternative (randomness), SWAP option might be prone to errors</p>	Very likely
Low engagement	<p>Checks: Survey was pretested (Attributes were chosen in cooperation), comments of the participants</p>	Unlikely

		<p>Results: nursery associations and comments provided by the participants in an open-ended question, indicate importance. Some respondents indicated that they would be interested in following the project's progress and indicated the project as "interesting". We observe that other open-ended questions were also answered (e.g., D4). Finishing times are not provided to check for irrational choices by participants</p>	(if participants engaged correctly, how were surveyors trained)
Attribute attendance	non-	<p>Check: Question on whether all or any of the attributes were ignored was included</p> <p>Result: 71% of respondents indicated that they considered all attributes. We mostly observe that the non-consideration of single attributes remains below 12% on average. 9% of the respondents were not sure whether they had considered any attributes. Romania acts as an outlier, whereas the majority of the respondents in France, Italy, and Germany seem to have considered all attributes (76%-80%).</p>	Unlikely
Bad responses (bots)		<p>Checks: high randomness of choices – displayed by an almost equal number of choices falling on the alternatives (bot fills in random) or all choices on one alternative only (e.g., bot was programmed to only select the first), no significant correlation between attribute levels and choices (comparison of model fits – null model and attribute only), very short response time</p> <p>Result: how were participants surveyed, and how does the platform check for bots, response time was not provided – this could not be verified</p>	Unknown
Design		<p>The design itself is D-efficient. The design aims to identify the number of choice sets necessary to identify the coefficients within the model. That the models solve (run) shows the design is not the cause.</p>	Unlikely

Detecting the Error - visual checks for high levels of randomness

Considering all choice sets (across all countries):

Alternative 1: 1,213 times (36.1 %)

Alternative 2: 1,205 times (35.9 %)

Alternative 3: 942 times (28 %)

The uniform distribution across all choice cards and alternatives at a large sample size implies that the randomization, not respondent behaviour, is the dominant driver of apparent randomness (= corrupted data).

Considering the code, randomization only occurs at two stages:

- First, when participants are randomly assigned a version (block). This most likely works, as we find responses for both blocks of the questionnaire versions for the same country.
- Second, the sequence in which the choice cards appear in relation to the initial design. (e.g., choice set 1 could appear as choice card 7).
- Third, it is randomly chosen whether the sequence of alternatives 1 and 2 is switched when it is graphically displayed to the participant (SWAP comment).

The question remains whether the code to implement the SWAP did not work correctly on all cards (explaining the equal distribution all over), or for most of the cards (explaining why some cards have a completely equal share for alternatives 1 and 2, with others being closer to it, and some even displaying distributions appearing more common).

For instance, card B1h Germany has 39% of choices falling on alternative 1, and 39% of choices falling on alternative 2. While B1n is closer to expectations (31% on alternative 1 and 56% on alternative 2). This speaks about the theory that not all cards are affected. Nevertheless, the code must be checked carefully for all the cards, especially when close to an equal distribution.

Checking the code – Potential Pitfalls:

The SWAP logic

Based on our understanding, it is intended that not only the alternatives on display switch positions, but that their radio button switches with them. This means that if alternative 1 is displayed in the second position, the underlying radio button still saves it as a choice for alternative 1.

In other words: “The SWAP logic was intended to randomize the **visual position** of Alternatives 1 and 2, while the radio button is meant to preserve their **semantic identity** in the data (i.e., the radio button for Alt 1 should still record a choice for Alt 1, even if it appears second). However, we cannot see how this is implemented for the radio buttons.

To-dos:

- While the ‘Ihre Wahl’ (Your choice) label is present in the survey interface, the underlying implementation of the input mechanism (e.g., radio buttons) is not fully visible in the provided logic file, making it difficult to verify whether the SWAP logic correctly reassigns the radio button values
- We must ensure that the radio buttons or selection inputs are correctly linked to the hidden field, capturing whether it was SWAPED
- The current script swaps the image but not the input elements
- Especially for the choice cards marked in red, this seems to have been wrongly implemented
- Detecting and learning about the error allows us to correct it

It is further important to note that when the reason for mislabeling is known, it can be trivial to address – Example: *the choice displayed first on the third questionnaire was assigned the wrong attributes. It was wrongly identified as choice set 2 from the design file, but it is choice set 3* (Stein, 2016). This would be easily fixable.

Having this randomisation step in here, and no information on whether a SWAP occurred or not, makes it impossible to restore the correct order. Can the information on whether it was SWAPED be added?

This would make it possible to check whether alternatives and levels are linked correctly, as long as the radio button mapping is clear, and how the radio buttons were treated when a SWAP option is chosen. In the previous survey, the SWAP is only saved as a hidden field, making restoration of the displayed order impossible.

The current implementation randomizes only the visual order of alternatives without ensuring that the corresponding input fields and recorded data are properly reassigned. Moreover, the SWAP flag is not stored in the dataset, making any post-hoc correction impossible.

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	Count	Italy			Romania			Germany			France			Difference		
		Count	Column N%	Difference	Count	Column N%	Difference	Count	Column N%	Difference	Count	Column N%	Difference			
B1b	1.00	68	33.2%	2.9%	18	36.0%	2.0%	7	17.9%	2.6%	23	35.9%	6.3%	20	38.5%	
	2.00	74	36.1%		19	38.0%		8	20.5%		27	42.2%		27	38.5%	0.0%
	3.00	63	30.7%		13	26.0%		24	61.5%		14	21.9%		12	23.1%	Code 3 = status quo
B1d	1.00	76	37.1%	-6.8%	18	36.0%	-6.0%	10	25.6%	-7.7%	29	45.3%	-17.2%	19	36.5%	5.8%
	2.00	62	30.2%		15	30.0%		7	17.9%		18	28.1%		22	42.3%	
	3.00	67	32.7%		17	34.0%		22	56.4%		17	26.6%		11	21.2%	
B1f	1.00	79	38.5%	-2.9%	20	40.0%	4.0%	10	25.6%	-12.8%	28	43.8%	-3.1%	21	40.4%	-1.9%
	2.00	73	35.6%		22	44.0%		5	12.8%		26	40.6%		20	38.5%	
	3.00	53	25.9%		8	16.0%		24	61.5%		10	15.6%		11	21.2%	
B1h	1.00	78	38.0%	-5.9%	21	42.0%	-10.0%	6	15.4%	15.4%	25	39.1%	0.0%	26	50.0%	-25%
	2.00	66	32.2%		16	32.0%		12	30.8%		25	39.1%		13	25.0%	
	3.00	61	29.8%		13	26.0%		21	53.8%		14	21.9%		13	25.0%	
B1j	1.00	71	34.6%	8.3%	21	42.0%	2.0%	5	12.8%	12.8%	26	40.6%	7.8%	19	36.5%	12%
	2.00	88	42.9%		22	44.0%		10	25.6%		31	48.4%		25	48.1%	
	3.00	46	22.4%		7	14.0%		24	61.5%		7	10.9%		8	15.4%	
B1l	1.00	73	35.6%	1.0%	19	38.0%	2.0%	7	17.9%	12.8%	27	42.2%	-6.3%	20	38.5%	0
	2.00	75	36.6%		20	40.0%		12	30.8%		23	35.9%		20	38.5%	
	3.00	57	27.8%		11	22.0%		20	51.3%		14	21.9%		12	23.1%	
B1n	1.00	69	33.7%	10.7%	24	48.0%	-8.0%	5	12.8%	17.9%	20	31.3%	25.0%	20	38.5%	6%
	2.00	91	44.4%		20	40.0%		12	30.8%		36	56.3%		23	44.2%	
	3.00	45	22.0%		6	12.0%		22	56.4%		8	12.5%		9	17.3%	
B1p	1.00	82	40.0%	-5.4%	22	44.0%	-10.0%	9	23.1%	-5.1%	30	46.9%	-10.9%	21	40.4%	5.8%
	2.00	71	34.6%		17	34.0%		7	17.9%		23	35.9%		24	46.2%	
	3.00	52	25.4%		11	22.0%		23	59.0%		11	17.2%		7	13.5%	
B1a	1.00	58	27.0%	14.4%	13	26.0%	22.0%	12	29.3%	-14.6%	18	27.3%	21.2%	15	25.9%	21%
	2.00	89	41.4%		24	48.0%		6	14.6%		32	48.5%		27	46.6%	
	3.00	68	31.6%		13	26.0%		23	56.1%		16	24.2%		16	27.6%	
B1c	1.00	68	31.6%	1.4%	14	28.0%	18.0%	11	26.8%	-4.9%	23	34.8%	-6.1%	20	34.5%	0.0%
	2.00	71	33.0%		23	46.0%		9	22.0%		19	28.8%		20	34.5%	
	3.00	76	35.3%		13	26.0%		21	51.2%		24	36.4%		18	31.0%	
B1e	1.00	88	40.9%	-6.5%	24	48.0%	-10.0%	9	22.0%	0.0%	28	42.4%	-6.1%	27	46.6%	-9%
	2.00	74	34.4%		19	38.0%		9	22.0%		24	36.4%		22	37.9%	
	3.00	53	24.7%		7	14.0%		23	56.1%		14	21.2%		9	15.5%	
B1g	1.00	81	37.7%	-3.7%	25	50.0%	-12.0%	14	34.1%	#####	21	31.8%	7.6%	21	36.2%	5%
	2.00	73	34.0%		19	38.0%		4	9.8%		26	39.4%		24	41.4%	
	3.00	61	28.4%		6	12.0%		23	56.1%		19	28.8%		13	22.4%	
B1i	1.00	79	36.7%	-2.3%	22	44.0%	-6.0%	11	26.8%	-2.4%	25	37.9%	-3.0%	21	36.2%	
	2.00	74	34.4%		19	38.0%		10	24.4%		23	34.8%		22	37.9%	2%
	3.00	62	28.8%		9	18.0%		20	48.8%		18	27.3%		15	25.9%	
B1k	1.00	78	36.3%	0.0%	21	42.0%	0.0%	8	19.5%	14.6%	25	37.9%	-9.1%	24	41.4%	
	2.00	78	36.3%		21	42.0%		14	34.1%		19	28.8%		24	41.4%	0.0%
	3.00	59	27.4%		8	16.0%		19	46.3%		22	33.3%		10	17.2%	
B1m	1.00	85	39.5%	-3.7%	23	46.0%	-2.0%	13	31.7%	-17.1%	22	33.3%	6.1%	27	46.6%	6.9%
	2.00	77	35.8%		22	44.0%		6	14.6%		26	39.4%		23	39.7%	
	3.00	53	24.7%		5	10.0%		22	53.7%		18	27.3%		8	13.8%	
B1o	1.00	80	37.2%	-5.1%	19	38.0%	6.0%	11	26.8%	-7.3%	27	40.9%	-7.6%	23	39.7%	-10%
	2.00	69	32.1%		22	44.0%		8	19.5%		22	33.3%		17	29.3%	
	3.00	66	30.7%		9	18.0%		22	53.7%		17	25.8%		18	31.0%	