NOVATERRA PROJECT

DELIVERABLE 5.1

Web-based tool with indicators to evaluate and predict level of adoption of the alternatives to contentious PPPs in Vineyard and olive groves

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Report information

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1.0 Executive summary

This study report fulfils **Deliverable 5.1** of the NOVATERRA project which aims to **evaluate** the **level of acceptance** of **alternatives to contentious plant protection products (PPPs)** in vineyards and olive groves. Ultimately, the results of the study are used to design a **web-based tool** capable of **predicting the level of adoption intentions** among **farmers** in the two sectors in the **EU Mediterranean regions.**

To achieve the objectives of the study, **qualitative and quantitative research was conducted using semi-structured interviews and structured survey questionnaires** to determine farmers' willingness to adopt selected alternative innovations as well as the factors influencing their adoption intentions.

Four alternative innovations that can be applied in **both vineyards and olive groves** to reduce the use of pesticides were selected from other work packages of the project. The selected innovations broadly involve **Smart farming (*e.g. smart canopy characterization*), Robotics (*e.g. Robot with mowing end-effector)*, Alternative treatment methods (*e.g. Bio-solutions*) and Improved soil management (*e.g. Cover crop with floral margins*)** that have been designed and their effectiveness and efficacy tested by partners of the project.

To unravel the dynamics of the **adoption decision-making process** and the roles of key stakeholders, semi-structured interviews involving 8 stakeholders each from the vineyard and olive grove sectors were conducted. The decision-making process as well as the role of **farmers in the adoption decision-making regarding plant protective products were probed and discovered**. Based on these findings, our evaluation of stakeholders' acceptance of the alternatives to contentious PPPs was narrowed down to farmers.

Using structured survey questionnaires designed based on **theory and literature review**, we evaluated the **willingness to adopt selected alternatives to PPPs by 354 farmers** and consequently designed a **predictive web-based tool to predict the adoption intention of farmers.**

Our results suggest that the majority of farmers have positive intentions to adopt the selected alternative pesticide-reducing innovations, albeit with varying levels of implementation on their farms. **Farmers' adoption decisions were significantly influenced by the investment costs associated with the innovations** with lower investment cost innovations attracting higher adoption interest.

Further analysis using the extended **Theory of Planned Behaviour (TPB)** revealed four key factors influencing adoption intentions: **attitude, perceived cost, perceived effectiveness of existing practices, and familiarity with sustainable innovations.** However, **Subjective norms and Perceived behavioural control which are fundamental constructs of the TPB framework**, were found to be statistically insignificant in terms of their influence on farmers' adoption intentions. This suggests that **social pressures and perceptions of ease or difficulty in implementing the alternative** innovations may not heavily influence the adoption decisions among vineyard and olive grove farmers

It is therefore recommended that interventions aimed at promoting the adoption of pesticide-reducing innovations focus on addressing factors such **as attitudes, cost perceptions, education, and information on the comparative advantages of alternative pesticide-reducing innovations over existing practices.**

Based on the study results, a **web-based tool capable of predicting farmers' adoption intentions** was developed, using the significant constructs identified in the study. This tool **offers valuable insights and decision-making support for stakeholders involved in promoting sustainable agricultural practices**.

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NOVATERRA : Integrated Novel Strategies for Reducing the Use and Impact of Pesticides, Towards Sustainable Mediterranean Vineyards and Olive Groves

2.0 Introduction and background

This report deals with subtask 5.2.1 under the NOVATERRA project that Seeks to find alternative ways to reduce the negative impact of pesticides in Mediterranean olive groves and vineyards. As part of the overall objective of the project, subtask 5.2.1 aims to evaluate stakeholders' acceptance of different alternatives to contentious plant protection products in the vineyards and olive groves.

Despite the increased levels of agricultural productivity in most advanced countries, the methods and technologies of production have often been scrutinized due to the challenges they pose to sustainable food production. It is therefore necessary that sustainable innovations and methods are adopted by farmers to ensure the balance between productivity and environmental sustainability.

In recent times, the use of contentious plant protection products (PPPs) also known as pesticides in the agricultural sector has raised several concerns due to the risk they pose to human health, impacts on biodiversity and the environment in general (Carvalho, 2017; Rani et al., 2021).

The use of pesticide (including herbicides in the inter-rows, fungicides, insecticides, and pheromone dispensers) in Mediterranean vines and olive groves are considered as threats to the conservation of biodiversity and sustainability of various ecosystem services provided by these crops (Chen et al., 2022). Although various regional and national policies have regulations governing the use of different pesticides, there are still concerns that current rates are not environmentally sustainable for which reason, further reductions are required to meet targets set under the EU Green Deal by 2030 (Rivas et al., 2021).

Under the NOVATERRA project, several alternatives to PPPs are being developed under the different work packages to augment vine and olive growers' efforts to achieve pesticide reduction targets, particularly within the Mediterranean regions. Some of these alternative innovations to PPPs include smart mapping tools, robots, bio-solutions and the use of cover crops with floral margins.

However, irrespective of how effective these innovations are in reducing pesticide use, they must be accepted by stakeholders including farmers in the sectors. It is therefore important that the project explores the willingness and intentions of farmers to accept the various pesticide-reducing innovations that are being developed under the project. This subtask empirically explores farmers' adoption intentions towards alternative innovations to PPPs. The study is based on the extended theory of planned behaviour model which is one of the most powerful and commonly applied theories to analyse intentions (Botetzagias et al., 2015; Garmendia-Lemus et al., 2024).

The study is carried out using two surveys: 1. a preliminary expert interview to identify the main decision-makers in the vine and olive sectors, and 2. an extensive survey involving 354 farmers based on the theory of planned behaviour to analyse the adoption intention of the decision makers (farmers) towards the various alternative innovations developed by the project. The study results are used to design a web-based tool that predicts the likelihood of adopting pesticide-reducing innovations.

The rest of this deliverable report is divided into objectives in section 1.2, the method which includes the survey design, data collection, and analysis procedures in section 2.0, the results in section 3.0, implication and conclusion in section 4.0 while cited references and other relevant information are presented in the last parts.

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3.0 Scope and Objectives

Although recent data are lacking in terms of pesticide use in the cultivation of different crops, historical datasets show that vineyards and olive groves are among the **pesticide-intensive crops in the EU** (Chen et al., 2022; Eurostat, 2017).

This is why the NOVATERRA project seeks **alternative innovations to PPPs** to promote **sustainable wine and olive cultivation** in the **Euro-Mediterranean region**.

However, promoting sustainable vine and olive production requires **knowing and understanding the intention and willingness of key decision-makers** particularly those at the cultivation level, **to adopt the different innovations**. Understanding the **adoption decision-making process, intentions** and the **factors** that facilitate **innovation adoption** would provide policymakers with the tools to drive **sustainable production** in the wine and olive oil sectors.

Although past studies have explored factors influencing farmers´ adoption decision of agricultural innovations (Rezaei et al., 2019; Sánchez-Toledano et al., 2017), limited studies have focused on innovations to reduce pesticides and even less so in the **vineyard and olive grove sectors**.

This study aims to understand the **adoption decision-making processes** and the **intentions** towards **alternative pesticide-reducing innovations** developed under the project in the vineyard and olive grove sectors.

Understanding the decision-making process, and adoption intention will help devise **appropriate strategies to promote alternatives to PPPs** that are crucial to **reducing the levels of pesticide use in the sectors**. Thus, a comprehensive understanding of the **adoption intentions** and the process can aid in streamlining and adapting policies and marketing activities to effectively address the challenges and opportunities in achieving the **EU targets of halving pesticide use by 2030**. Furthermore, both member states and those at the EU level can benefit from acquiring a deeper understanding of the various factors that influence the adoption of these **alternatives to PPPs.**

Therefore, this subtask focuses on the following objectives

- Identify the adoption decision-making process and decision-makers regarding innovation adoption at the farm level in the vineyard and olive grove sector
- Determine the willingness and adoption intention of decision-makers regarding alternative pesticide-reducing innovations
- Develop a tool to predict the adoption intentions of decision-makers based on the results obtained

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4.0 Method

The objectives of the task were achieved using primary data collected through stakeholder interviews and farmer surveys. The stakeholders' interview was used to identify each sector, the farmers, as well as other relevant decision-makers that are responsible for selecting the plant protection treatment at the farm level. The farmers' survey was then conducted to assess the willingness and adoption intention of farmers towards alternatives to PPPs. Below is a summary of methods adopted to achieve the objectives of the task.

4.1 Identifying decision-makers in the vineyard and olive grove sector

1. In the first step, a total of 16 key stakeholders in the vineyard and olive grove sectors were identified from France, Greece, Portugal and Spain. The stakeholders were selected from a pool of stakeholder networks established by the NOVATERRA project. The selected participants included farm managers, directors, farmers, researchers, and agricultural engineers among others. Open-ended questions were asked during the survey interviews to identify how decisions regarding the adoption/selection of plant protection are made at the farm level as well as the key decision-makers. The specific questions include:

a) Who is responsible for selecting new plant protection treatments at the farm level?
b) Who decides on whether an innovation or a new treatment is adopted at the farm level?
c) What roles do farmers play in the adoption process at the farm level?
d) What key factors determine the decision to adopt innovations or otherwise?

2. Following the initial stakeholder interviews, an extensive survey involving mainly 354 farmers and associated decision-makers was conducted to ascertain the adoption intentions towards alternatives to PPPs. The survey was conducted through the QUALTRICS© platform, a trusted and reliable survey management tool.

3. The survey was divided into 4 blocks with each section dealing with aspects such as respondents' characteristics, willingness to adopt questions as well as factors predicting intentions based on the theory of planned behaviour.

4. The first section involves introducing farmers to the aims of the survey and the NOVATERRA project. All participants were provided with information on the project and the purpose of the survey and were consequently given the option to participate through a consent form. Participants were guaranteed their privacy and anonymity under the General Data Protection Regulation of the European Union.

5. In the second section, the participants were introduced to four alternative pesticide-reducing innovations developed under the NOVATERRA project from work packages two, three and four. The four innovations are classified under smart mapping, robotics, bio-solution, and cover cropping. All four selected alternative innovations could be used by farmers in both sectors (i.e. vineyard and olive groves) to optimize/reduce the use of contentious plant protective products. Participants were given information on the innovation, which included the **description**, the **initial investment cost**, **maintenance cost**, and the **advantages over existing methods**. Refer to **Table 3** for details of each innovation as presented in the survey. After the detailed information on each innovation, participants were asked about their willingness to adopt them and if yes, on what percentage of the farm area (i.e. either 20%, 40%, 60%, 80% or 100% of the farm). Options were provided for comments following their decisions on willingness to adopt alternative innovations or otherwise.

6. Given that farmers' adoption of the alternatives to contentious plant protection products could affect farmers' farm income, incentives to encourage the adoption alternative innovations may be

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necessary (Golub et al., 2012). One such incentive could be consumers' willingness to pay higher price premium for the products resulting from the alternatives to PPPs. This is because higher willingness to pay by consumers can partially offset the costs of adopting pesticide-reducing innovations, see (White & Brady, 2014). For this reason, we delve deeper into farmers' willingness to adopt using the results from **deliverable 5.3** of the NOVATERRA project. The outcome of this deliverable revealed that consumers are willing to pay a premium for wines and olive oil produced from alternative methods that reduce pesticide use if the reduction can be clearly communicated to consumers. Therefore, **using consumers' willingness to pay more as incentives to farmers**, we asked the participants if their adoption decision would change given that consumers are willing to pay more for wines and olive oil produced from sustainable alternative innovations.

7. In the third section, participants were presented with statement indicators to measure their attitude, subjective norms, perceived behavioural control, the perceived cost of the alternative pesticide-reducing innovations, and perceived effectiveness of existing practices among others. In addition, participants were given statements on their adoption intentions for pesticide-reducing innovation. All the statements were ranked on a 7-point Likert scale of agreement (from strongly agree to strongly disagree). The theory behind this framework of questions is the theory of planned behaviour, which is explained in the subsequent section.

8. In the final section of the survey, general information on the sectors and farms of participants including their farm size, management practice, major challenges, and source of trusted information for decision-making were solicited.

The survey was carried out between November 2023 and February 2024 with the help of partners of the project. The results of the survey are used as a baseline to develop a web-based tool to predict the likelihood of adoption of alternatives to contentious plant protective products in the vineyards and olive groves.

4.2 Understanding the adoption intentions of farmers: The Theory of Planned Behaviour

The process of adopting innovation involves incorporating new ideas, products, services, or technology into existing practices or systems as intended by the developers (Rogers 1983). Adoption intention refers to the readiness or willingness of the target of the innovation to adopt it. Despite the rapid and widespread emergence of sustainable farming technologies and innovations, their adoption by farmers often faces challenges, resulting in delays or, in some cases, outright rejection by the target farmers.

The successful implementation of sustainable measures, such as pesticide reduction therefore depends highly on the acceptance and adoption of alternative pesticide-reducing innovation by farmers. Determining the adoption intentions of farmers towards technologies and innovations has become a popular theme in research literature with numerous studies discussing the factors influencing farmers' adoption of pro-environmental behaviours and technologies (e.g. Castillo et al., 2021; Colin Castillo et al., 2022; Garmendia-Lemus et al., 2024).

Several well-known theories have been used to study and explain adoption intention and behaviour among farmers. Among them are the Technology Acceptance Model (TAM) e.g. (Amin & Li, 2014; McCormack et al., 2022), the Diffusion of Innovations Theory (DIT) e.g. (Matthews, 2017), The Theory of Reasoned Action (TRA) e.g. (Morais et al., 2018).

However, in recent times, the Theory of Planned Behaviour (TPB) is one of the most powerful and commonly applied theories (Botetzagias et al., 2015; Wang et al., 2023). The theory of planned behaviour is an extension of the theory of reasoned action, developed in response to the limitations of TRA in addressing behaviours that people have limited control over, like time and opportunity (Ajzen, 1991). The theory postulates that an individual's intention can be predicted with high accuracy from attitudes toward a certain behaviour, perceived behavioural control (PBC), and subjective norms (Ajzen, 1991; Ajzen et al., 2004)

Under the TPB, an individual's intention to fulfil a given action is the central factor. According to Conner & Armitage (1998), intention demonstrates individuals' motivation in terms of their conscious decision or plan to exert effort to perform specific behaviours. Thus, a greater probability of performance can occur from an individual's stronger intention to engage in a behaviour (Ajzen, 1991).

The prediction power of TPB has been demonstrated in analysing various farmers' behaviours, including their ability to adapt to natural disasters and climate change, embrace irrigation technologies, adopt sustainable and conservation agriculture practices, and engage in other pro-environmental behaviours.(Dong et al., 2022; Wang et al., 2023; Zhang et al., 2020).

However, due to the limitations of the TPB model such as relying on beliefs only, focusing on self-interest, and neglecting moral norms (see e.g. Zhang et al., 2020), it is suggested to integrate different non-excludable models and factors according to theoretical and practical considerations.

The type of model and factors to integrate into TPB to improve its predictive powers is therefore important and depends on several considerations. Considering the alternative alternatives to PPPs (i.e. pesticide-reducing innovations) that involve the use of new and sustainable pest control technologies, some influential factors of adoption need to be considered as outlined below.

4.2.1 Theoretical model and hypotheses

The core of the TPB proposes that an individual's intention can be predicted with high accuracy from attitudes (ATD) toward a certain behaviour, perceived behavioural control (PBC), and subjective norms (SN) (Ajzen, 1991, 2002).

ATT presents the degree of individual assessment as favourable or unfavorable (Ajzen, 1991). An individual's attitude towards a behaviour depends on the overall evaluation of that behaviour and belief in its desirable outcomes and thus, a positive ATD towards a particular behaviour can therefore lead to a higher intention of performing that behaviour (Gao et al., 2017; Tan et al., 2017). Considering alternatives to PPPs, vine and olive growers will intend to adopt them only if they believe that using these alternatives would be beneficial or lead to better outcomes. Hence, ATD can be considered as an important factor explaining intentions to adopt pesticide-reducing innovations.

PBC is the perceived difficulty or ease of performing a specific behaviour (Ajzen, 2002), used as an approximation to one's actual behaviour control (Wang et al., 2023). Precisely, PBC represents individuals' engagement in a given behaviour based on their beliefs in the possibility of access to the required resources and opportunities (Rezaei et al., 2019). Generally, farmers who perceive higher control capacities tend to adopt relevant measures (Savari & Gharechaee, 2020).

SN refers to the personal perception of behaviour under the influence of other people's attitudes. SN therefore shows how individuals weigh the expectations of the "important others" (Castillo et al., 2021). It is usually expected that high cognition of SN can increase behavioural intention (Wang et al., 2023).

Following Rezaei et al. (2019) and Wang et al. (2023), we assume that intention would provide sufficient information on farmers' behaviours (i.e. adoption of alternative pesticide-reducing innovations) since intentions are strong predictors of pro-environmental behaviour.

In light of the original TPB framework, we have formulated the following hypotheses:

H1-H3: Farmers' ATT(H1), PBC (H2) and SN (H3) toward alternatives to PPPs bolster their Intention (INT) to adopt these innovations

4.3 Extending the TPB with additional constructs

4.3.1. Perceived costs (PC) as an additional construct

As identified by previous studies, it is common for farmers to face several economic uncertainties when considering the adoption of new and particularly, conservative practices (Gao & Arbuckle, 2022; Garmendia-Lemus et al., 2024). The potential barriers to the adoption of agricultural technologies among farmers include the cost of innovation and its implications on future operations, which arise due to the uncertainty associated with the adoption process (Marra et al., 2003).

Considering the alternative innovations to contentious PPPs used by vine and olive farmers, the adoption of the alternative innovations could directly impact farmers' operating costs regarding pest control and ultimately affect their economic goals (Chèze et al., 2020). Therefore, to understand the adoption intention, it is in the right practice to establish the relations between how farmers perceive the cost of the alternative pesticide-reducing innovation and how this impacts their adoption intention in the TPB framework. For this reason, we include the perceived costs (PC) defined as the extent to which farmers perceive the disadvantages of adopting pesticide-reducing innovations concerning their pest control costs (Garmendia-Lemus et al., 2024). The theory of perceived utility serves as the foundation for the constructs, which encompass the subjective perception of the advantages, usefulness, contentment, or worth (whether positive or negative) that individuals anticipate obtaining from a product (Adnan et al., 2019). Our fourth hypotheses state that

H4: The perceived cost associated with alternatives to PPPs will bolster farmers' intention (INT) to adopt pesticide–reducing innovations

4.3.2. Perceived effectiveness of existing practice (PE) as an additional construct

Existing farm practices can significantly influence the adoption of innovations among farmers. Research findings suggest that farmers who have effective routines and practices may face challenges in adopting new technologies due to the inertia from the effectiveness of the existing practice (Rizzo et al., 2024). This is because farmers considering adopting an innovation are faced with an uncertain environment and hence are forced to compare the expected utility or relative advantages of the available alternatives (Kaine & Wright, 2022; Kuehne et al., 2011; Roussy et al., 2017).

Concerning pesticide-reducing innovations in vineyards and olive groves, it is important to highlight that they are not innovations to solve a new problem but rather alternatives to promote sustainable vine and olive cultivation. Farmers' willingness to adopt alternative innovations therefore partially depends on the effectiveness of their existing practices and systems of pest control.

As explained by Bandura's social cognitive theory, a person's past experiences determine whether behavioural action will occur (Bandura, 2001; Bandura et al., 1999). These past experiences influence reinforcements, expectations, and expectancies, all of which shape whether a person will engage in a specific behaviour. Under the social cognitive theory, farmers' perceived effectiveness of their existing

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practice could be described under the self-efficacy constructs. Self-efficacy refers to the level of a person's confidence in his or her ability to successfully perform a behaviour. In the context of pest control, self-efficacy would entail the belief that the methods a farmer is currently employing are effective in managing or controlling pests. This belief can influence a person's motivation, persistence, and decision-making regarding the adoption of alternative innovations (Rosário et al., 2022). Farmers' perception of the effectiveness of their current practices can have a negative impact on their adoption intentions towards alternative practices to PPPs. To test this hypothesis, we extended the TPB to include the perceived effectiveness of existing practices.

H5: Perceived effectiveness of existing methods of pest control among farmers impacts the intention(INT) to adopt pesticide-reducing innovations

4.3.3. Familiarity with sustainable alternative innovation (FST) as an additional construct

Lack of familiarity with proposed innovations has been highlighted as one of the important factors that significantly influence the adoption and diffusion of innovations among farmers (Dearing & Meyer, 1994). This is because familiarity influences the perception of the benefits, costs, complexity of use and implementation of innovations as well as its integration into their existing practices (Jameson et al., 2024; Kaine & Wright, 2022; Roussy et al., 2017)

Considering the four alternative innovations presented in this study (smart mapping, robotics, biosolution and cover crops) familiarity could be a key factor to farmers´ adoption intentions. For instance, a farmer who is not familiar with how smart canopy characterization (mapping) is used to optimize the spray volume of pesticides may have some reluctance to adopt such innovations due to potential operational/implementation challenges.

The inclusion of FST as an additional construct is based on the mere exposure effect or the familiarity principle. According to the mere exposure theory, repeated exposure to an object enhances its affective attitude (Zajonc, 1968). It is found that repeated exposure (familiarity) to agriproducts evokes positive emotions and consequently bolsters intentions to use the products (Kim et al., 2019).

Generally, farmers with a high level of familiarity with alternatives to PPPs are likely to have increased confidence in their ability to adopt it, they would feel that they have the necessary skills and knowledge to use it effectively. Thus, we include the FST as an additional construct in the TPB to test the hypothesis that

H6: Farmers' familiarity with alternatives to PPPs bolsters their Intention(INT) to adopt pesticide-reducing innovation.

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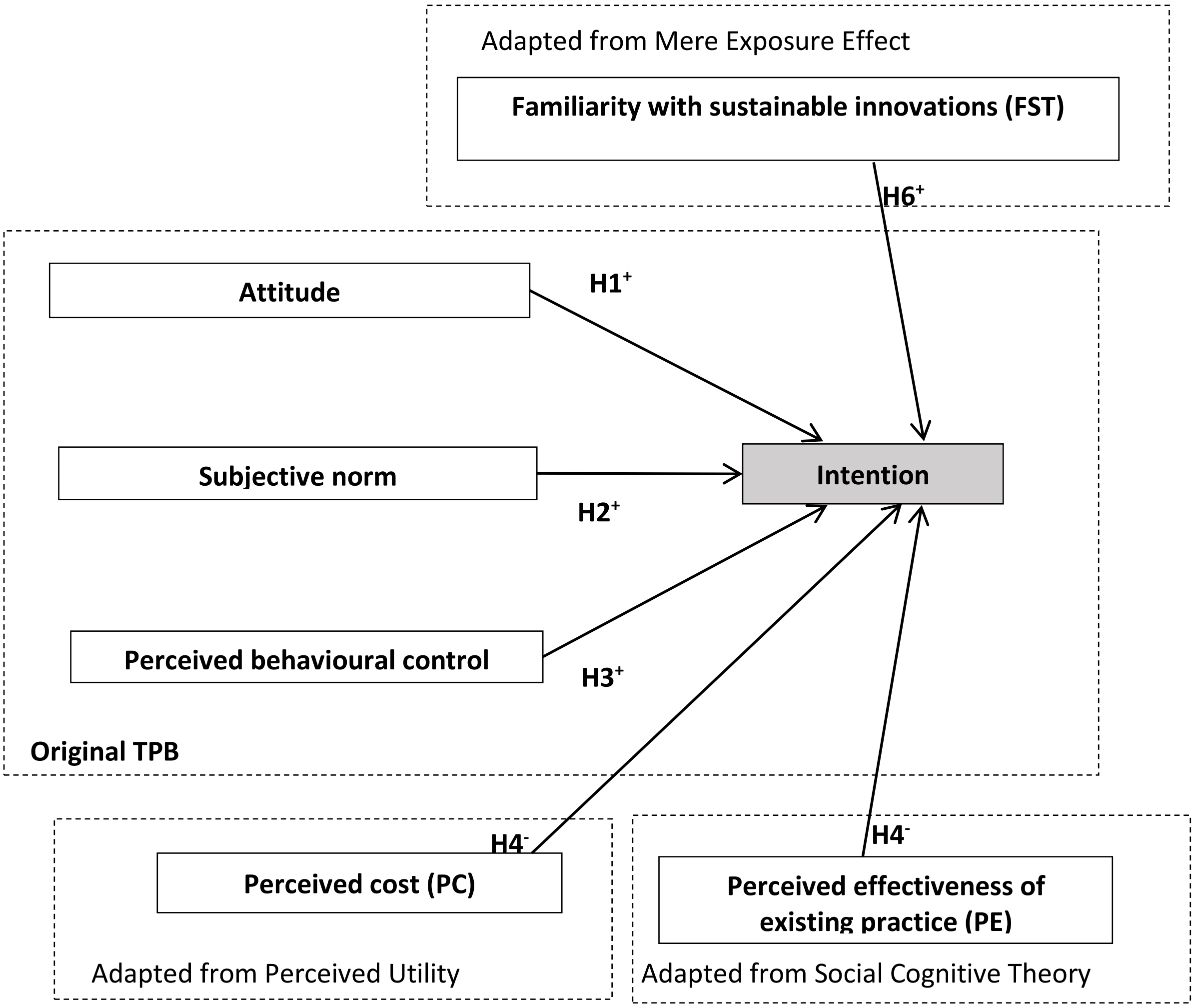

Figure 1. The theoretical model and hypotheses

4.4 Data collection

As mentioned in the methods summary section, this study conducted a two-stage qualitative-quantitative survey. The first stage was a qualitative survey in September 2022. Through semi-structured interviews, we obtained information on the adoption decision-making process regarding plant protection products (pesticides) in the vineyards and olive grove sectors. We observed that several actors might be involved in the decision-making process when selecting pesticides at the farm level. We found that farm *managers, foremen, farmers, technical advisors from cooperatives, commercial companies, extension officers, salesmen, technicians, phytosanitary regulators and specialized governmental institutions, all play a part in the decision-making process.* The specific actor's role in the final decision depends on factors such as the farm's size, the farmer's experience, and the group or association under which the farm operates. For instance, on small farms, the farmers typically make the decision, while on larger farms with managers, technicians, and directors, the decision to adopt new treatment innovations is often a combined decision made by the experts in charge.

We noted that the farmers of vineyards and olive groves always have a role in the adoption decision process but their specific role in the adoption process depends on many factors. Some may act as mere experiment facilitators in innovation trials while some are regarded as the final decision makers.

Based on the results of the semi-structured interview, a second-stage structured questionnaire survey, involving mainly farmers, was conducted between November 2023 and February 2024. The questionnaire was developed based on literature (Rezaei et al., 2019; Savari and Gharechaee, 2020; Zhang et al., 2020; Wang et al., 2023) and contextualized based on the Theory of planned behaviour (TPB) regarding pesticides used in vineyards and olive groves.

The questionnaire comprised the measurements of variables about farmers' willingness to adopt alternative innovations, the adoption intentions based on the TPB model and sections on the sociodemographic, perceptions and attitudes towards pesticide use among others.

Farmers' willingness to adopt each alternative innovation was measured by presenting a detailed description of selected alternative innovations (*See* Table 3). Consequently, the farmers were asked what proportion of their farmland they were willing to implement the innovation. Thus, each innovation was described separately, following which the response for their willingness to adopt was elicited. Figure 2 below shows a sample of the stages through which farmers' willingness to adopt each alternative innovation was measured.

As shown in the last section of Figure 2, all participants who indicated their unwillingness to adopt a particular innovation were asked to state the reasons behind their decision. Among the possible reasons are suitability to farm, expensiveness, and difficulty of implementation among others. All participants were also given the option to provide additional comments about each alternative innovation in the survey.

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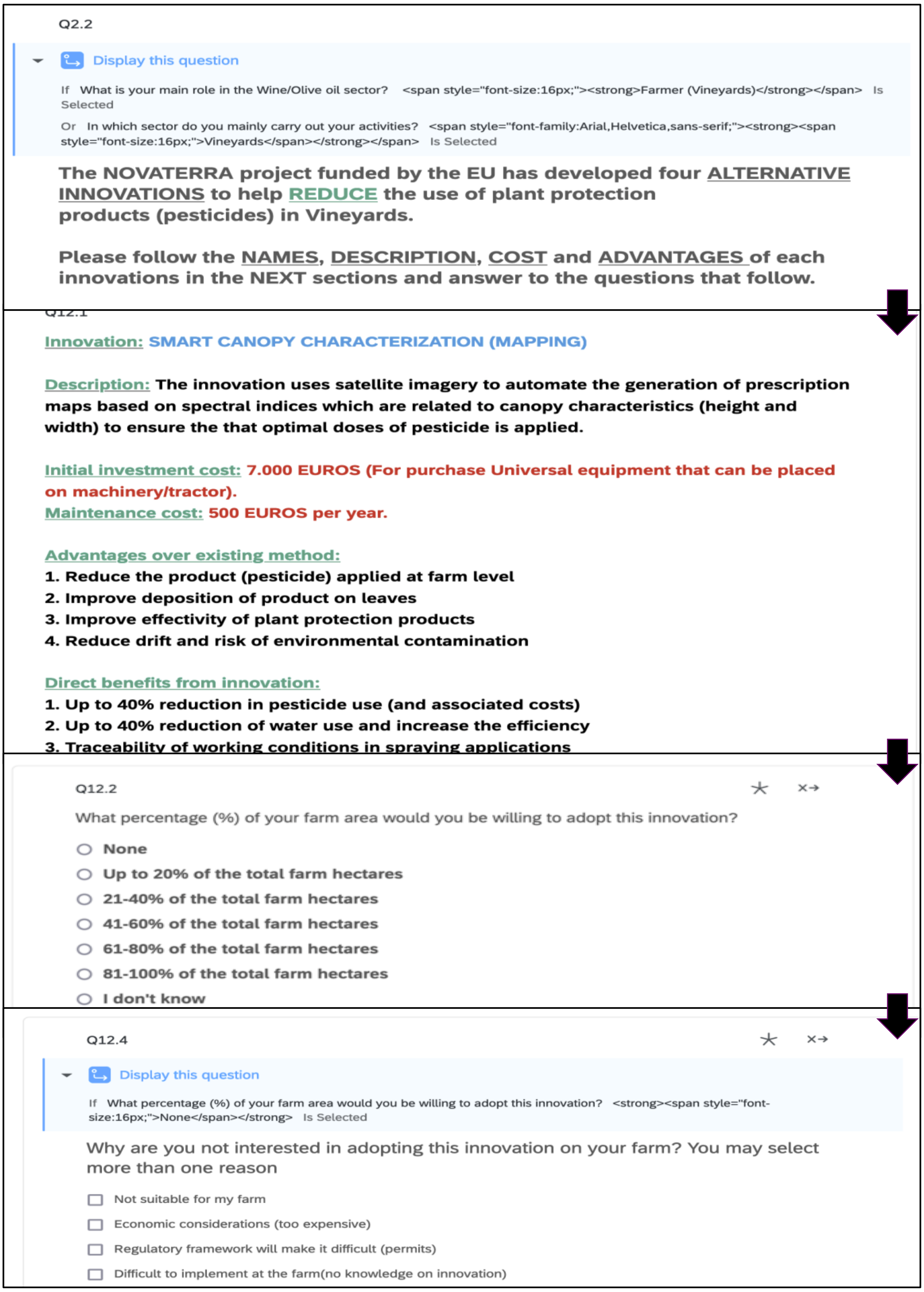
Q2.2

Display this question

If What is your main role in the Wine/Olive oil sector? Farmer (Vineyards) Is Selected

Or In which sector do you mainly carry out your activities? Vineyards Is Selected

The NOVATERRA project funded by the EU has developed four ALTERNATIVE INNOVATIONS to help REDUCE the use of plant protection products (pesticides) in Vineyards.

Please follow the NAMES, DESCRIPTION, COST and ADVANTAGES of each innovations in the NEXT sections and answer to the questions that follow.

Q12.1

Innovation: SMART CANOPY CHARACTERIZATION (MAPPING)

Description: The innovation uses satellite imagery to automate the generation of prescription maps based on spectral indices which are related to canopy characteristics (height and width) to ensure the that optimal doses of pesticide is applied.

Initial investment cost: 7.000 EUROS (For purchase Universal equipment that can be placed on machinery/tractor).
Maintenance cost: 500 EUROS per year.

Advantages over existing method:
1. Reduce the product (pesticide) applied at farm level
2. Improve deposition of product on leaves
3. Improve effectivity of plant protection products
4. Reduce drift and risk of environmental contamination

Direct benefits from innovation:
1. Up to 40% reduction in pesticide use (and associated costs)
2. Up to 40% reduction of water use and increase the efficiency
3. Traceability of working conditions in spraying applications

Q12.2

What percentage (%) of your farm area would you be willing to adopt this innovation?

- None
- Up to 20% of the total farm hectares
- 21-40% of the total farm hectares
- 41-60% of the total farm hectares
- 61-80% of the total farm hectares
- 81-100% of the total farm hectares
- I don't know

Q12.4

Display this question

If What percentage (%) of your farm area would you be willing to adopt this innovation? None Is Selected

Why are you not interested in adopting this innovation on your farm? You may select more than one reason

- Not suitable for my farm
- Economic considerations (too expensive)
- Regulatory framework will make it difficult (permits)
- Difficult to implement at the farm(no knowledge on innovation)

Figure 2. Sample section of the questionnaire on willingness to adopt alternative innovation

The adoption intention and its determinants under the TPB were measured with latent variables comprising 18 indicator items measuring six constructs – INT, ATD, SN, PBC, PE, and FEST (as shown in Table 2). The 18 indicator items were statements measured with Likert scale of agreement ranging from 1 to 7 (where 1 = strongly disagree and 7 = strongly agree). Figure 3 below shows a sample of the indicator items used to measure farmers´ adoption intention.

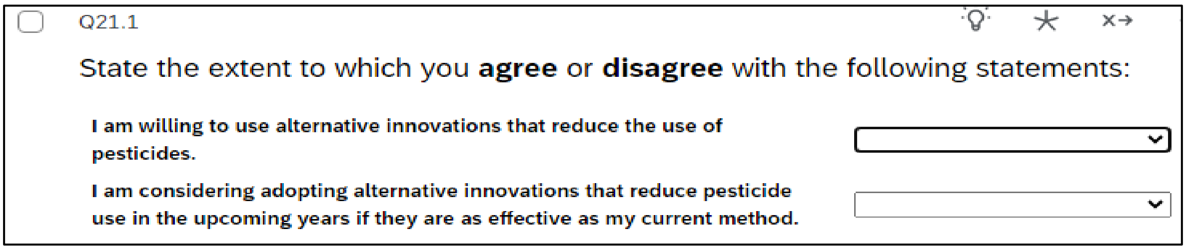

Figure 3. A sample of the questionnaire with statements measuring adoption intention

The questionnaire was reviewed by experts including partners of the NOVATERRA project and was pre-tested in the experimental survey of 25 target farmers in the five case study Member states. All partners of the NOVATERRA project also answered the final version of the questionnaire prior to its launch. The final version of the questionnaire was approved and launched in November 2023 through the Qualtrics© survey platform. The main data collection activities took place during the various workshops, seminars and focus group events organized by partners of the project.

A combination of purposive (i.e. selection of vineyard and olive grove farmers through the NOVATERRA partners and stakeholder network, seminars and workshops) and snowball (i.e. asking the selected farmers to refer other farmers in the sector) sampling methods were applied to identify vineyard and olive grove farmers in the five Euro-Mediterranean Member states. Participation was voluntary with the purpose and objective of the survey explained to participants at the beginning. The anonymity and privacy of participants were guaranteed under the EU General Data Protection Regulation. The survey was CAPI-based (Computer-Assisted Personal Interviewing) with participants being able to participate using electronic gadgets including Mobile phones.

Overall, 362 farmers participated in the survey with recorded partial responses and some logical inconsistencies. After cleaning data, the final sample remained 354 responses, which was sufficient for our analysis (see, Wang et al., 2023). The distribution of the data among the five case study member states is presented in Table 1 below. The link to the survey is also shown below the table.

Table 1. Data distribution from the survey

Country	France	Greece	Italy	Portugal	Spain
Total Sample	29	38	36	123	136
Total cleaned data	**354**				

SURVEY LINK

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4.5 Data analysis

The study adopted the Structural equation modelling (SEM) technique, which is suitable for the analysis of complex cause-effect structures such as the TPB studies and adoption research (Garmendia-Lemus et al., 2024; Wang et al., 2023). Preliminary tests are first conducted to confirm data compatibility with SEM. The normality of the data is checked using skewness, the multicollinearity is checked according to the criteria proposed by Grewal et al. (2004), to verify the acceptability of applying SEM. As noted by Kline (2023), SEM requires a minimum sample size of 200, and hence, our sample size of 354 was sufficient.

The SPSS software version 29 and SmartPLS© software version 4 are used for the analysis. Confirmatory factor analysis (measurement model) and the structural model are used to test the relationships in the hypothesized constructs in the TPB.

Convergent validity is measured using the Factor loading and Average Variance Extracted (AVE) (Fornell & Larcker, 1981), and items with factor loading lower than 0.5 are eliminated. As noted in the literature, more items lead to better construct representation and higher reliability (Marsh et al., 1998). However, according to Eisinga et al. (2013), with the acceptable value of Cronbach's alpha, one could confirm the reliability and trust of their instruments. Goodness-of-fit results are used to confirm the validity of the structural model by measuring the normed Chi-square (Chi^2), normed fit index[2] (NFI), standardized root mean square residual[3] (SRMR), Bootstrap[4]-based test for the exact overall model fit (i.e. the squared Euclidean distance-d_ULS and geodesic distance-d_G) [see Bollen & Stine (1992), Henseler et al. (2015), (Dijkstra & Henseler, 2015)]

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[2] The NFI is defined as 1 minus the Chi^2 value of the proposed model divided by the Chi^2 values of the null model. The closer the NFI to 1, the better the fit. NFI values above 0.9 usually represent acceptable fit

[3] The SRMR is the difference between the observed correlation and the model implied correlation matrix. A value less than 0.10 or of 0.08 (in a more conservative version; see Hu & Bentler (1999) are considered a good fit

[4] The bootstrap-based test for the exact overall model fit tests the statistical (bootstrap-based) inference of the discrepancy between the empirical covariance matrix and the covariance matrix implied by the composite factor model. Note that the value of the d_ULS and d_G in itself do not pertain any value but requires Bollen-Stine bootstrapping results [see Bollen & Stine (1992) for more] to allow for an interpretation of results.

Table 2. Constructs of the Theory of Planned Behaviour and their measuring indicators that were included in the questionnaire and evaluated on a agreement scale from 1 to 7

Construct and measurement indicators	
Attitude towards alternative innovations	
ATD1	I believe that using alternative innovations that reduce pesticide use will lead to better environmental outcomes.
ATD2	I prefer the characteristics of the alternative innovations to reduce pesticide use more than existing pest control methods.
Perceived behavioural control	
PBC1	I have the skill and knowledge to use alternative innovations of pest control instead of my current method without additional effort.
PBC2	I have enough information about the properties and features of alternative innovations that can be used to reduce pesticide use on my farm.
Subjective norms	
SN1	Most people whose opinions are important to me suggest using alternative innovations to reduce pesticides.
SN2	Agricultural experts/my trusted advisors consider that alternative innovations to reduce pesticide use will be beneficial for my farm.
SN3	Agricultural input providers will approve the use of pesticide-reducing alternative innovations on my farm instead of my current method.
SN4	My colleague farmers will use pesticide-reducing alternative innovations so I will not use them.
SN5	Consumers of my products suggest using pesticide-reducing innovation.
Perceived effectiveness of existing practice	
PE1	I consistently see positive results in pest control and crop yield from my current pesticide practices.
PE2	I believe that the existing pesticide application methods I use are very successful in maintaining the health of my crops.
PE3	I am satisfied with my current pest control practices because they provide adequate protection for my crops.
Familiarity with sustainable innovations/solutions	
FST1	The use of satellites with smart mapping tools are pest control alternative that I am aware of
FST2	I am familiar with the use of robots is a more sustainable pest control alternative.
FST3	The use of bio-solutions in modern farming activities is something known to me
FST4	The use of cover crops with floral margin is a sustainable pest control alternative that I know
Intention to adopt pesticide-reducing innovations	
INT1	I am willing to use alternative innovations that reduce the use of pesticides.
INT2	I am considering adopting alternative innovations that reduce pesticide use in the upcoming years if they are as effective as their current treatment methods.

Table 3. Description of selected alternative pesticide-reducing innovations in the NOVATERRA project

Innovation	1. Smart canopy characterization	2. Robot (modular-e) with mowing end-effector	3. Bio-solutions	4. Cover crop with Floral margins
Description	The innovation uses satellite imagery to automate the generation of prescription maps based on spectral indices which are related to canopy characteristics (height and width) to ensure that optimal doses of pesticide are applied.	A robot with soil sensors capable of removing weeds and providing precise soil fertilization/treatment.	Combining bio-stimulants and bio-control products with low doses of copper and sulphur formulations to fight diseases	Involves the introduction of beneficial plants (shrubs, flowers) among the crop lines (olive groves or vineyards) to attract the natural enemies of pests.
Initial investment cost	7.000 EUROS (Universal equipment purchase that can be placed on machinery/tractor)	20.000 EUROS for the purchase of the Modular-E Robot and Mowit tool	None	3.600 EUROS per hectare to establish
Maintenance cost	500 EUROS per year	250 EUROS per year	20% higher than the existing chemical treatment method	525 EUROS per hectare per year
Direct benefits from innovations	1. Up to 40% reduction in pesticide use (and associated costs) 2. Up to 40% reduction of water use and increase the efficiency 3. Traceability of working conditions in spraying applications	1. Reduce herbicide cost by up to 80% for weed control between tree lines 2. Improve soil management and soil compaction 3. Reduce labour costs on fertilization and weed control by 40% 4. Preservation of the soil structure and life	1. Higher product prices due to sustainable certifications 2. Reduce the use of pesticides by up to 30%	1. Reduced 30% fertilization inputs through natural nitrogen cycles 2. Control pests naturally through increased inter-species competition 3. Protection against soil erosion and water preservation 4. Increased soil health and biodiversity which leads to increased nutrient absorption
Advantages over existing methods	1. Reduce the product (pesticide) applied at farm level 2. Improve deposition of product on leaves 3. Improve the effectiveness of plant protection products 4. Reduce drift and risk of environmental contamination	1. It works completely automated 2. It can be controlled/connected to almost any Decision Support Systems 3. No herbicide required (just mechanical weeding) 4. It can be extended with other functionalities such as precision spraying and pruning	1. Adapted to the disease pressure based on the rate of prevalence 2. Agro-ecologically friendly	1. Increase biodiversity and minimize pest population 2. Improve soil health 3. Increase yield and quality of crops 4. Efficient and involves low cost

5.0 Results

5.1 Descriptive statistics

5.1.1 Country of participants

As shown in Figure 4, the majority of the participants in the study resided in Spain and Portugal with a combined percentage of approximately 83%. The remaining participants are distributed among Italy, Greece and France comprising approximately 10%, 9% and 8% respectively.

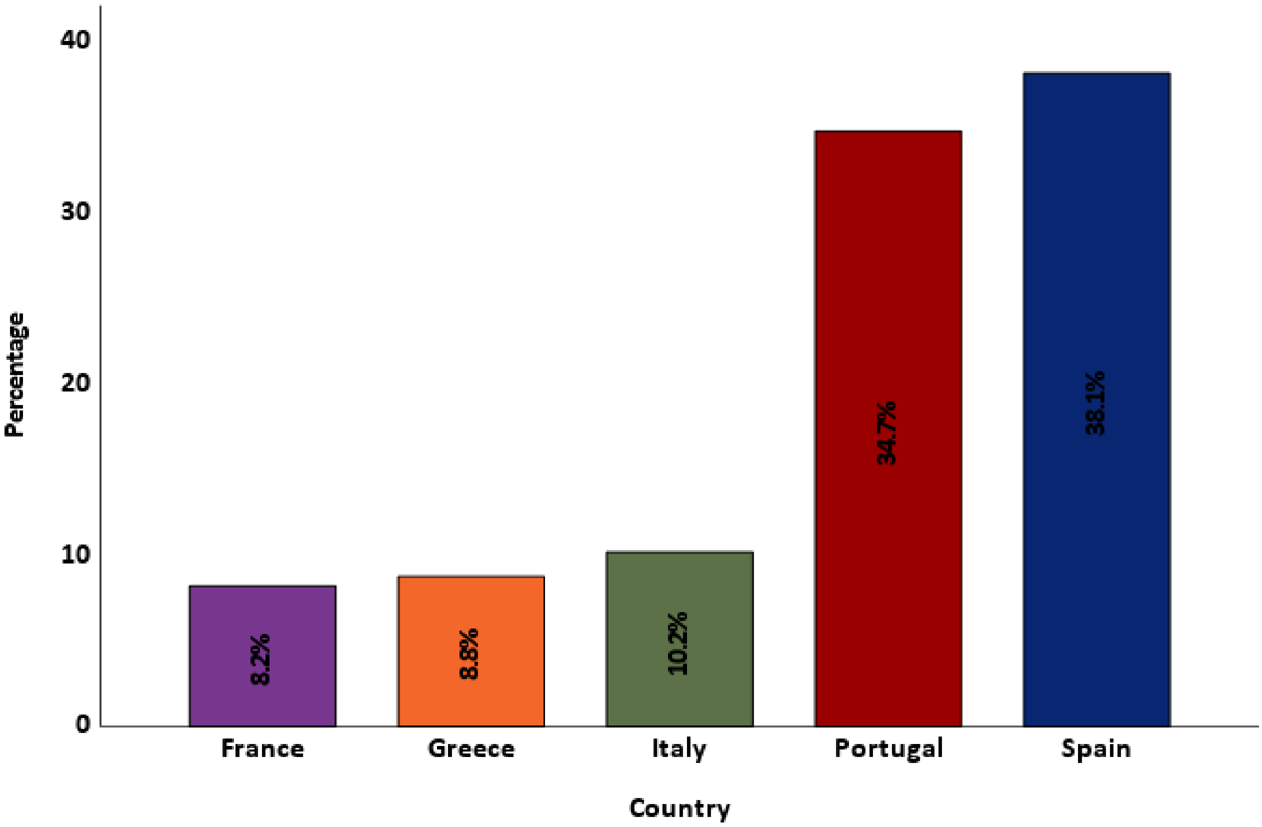

Figure 4. Country of residence of participants

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5.1.2 Gender

In terms of gender, the majority of the participants were males, accounting for nearly 80% while females make up 20%. The 4:1 male-to-female ratio of participants reflects the distribution of gender in the EU's Agricultural sector as farming remains a male-dominated profession.

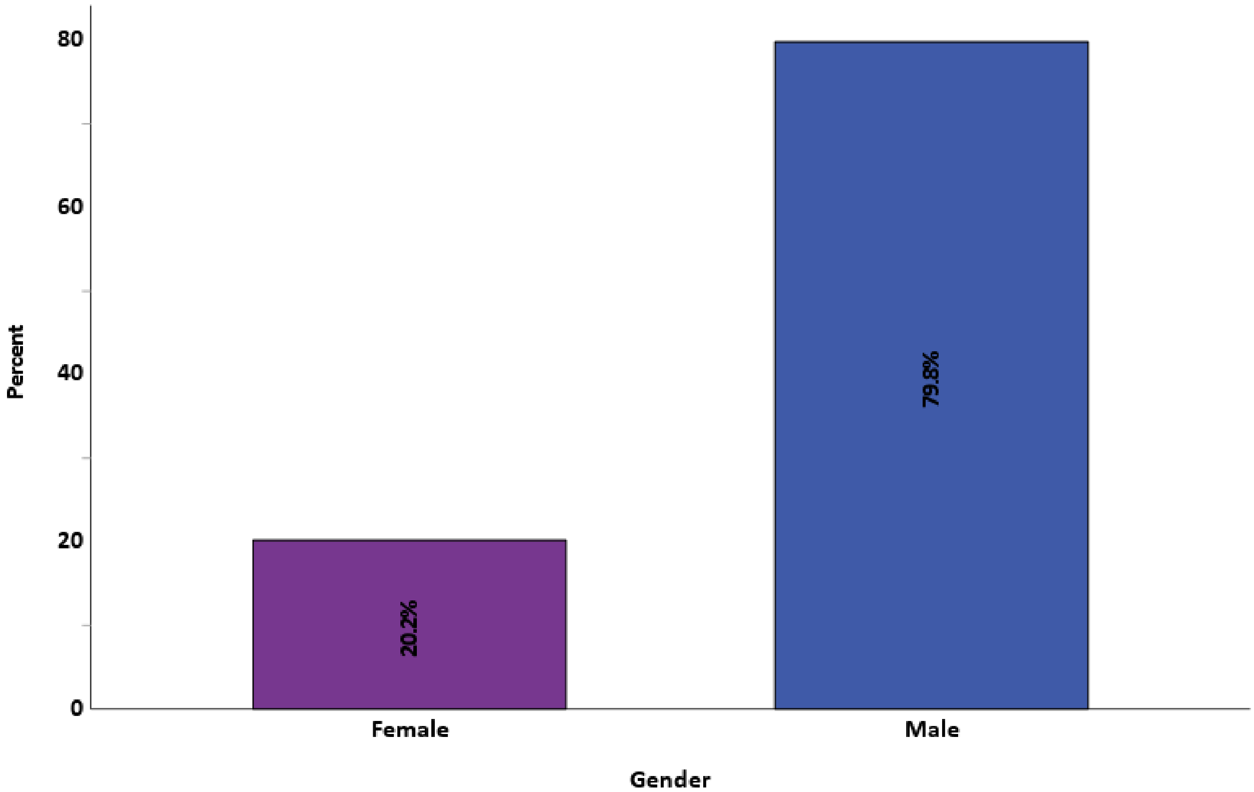

Figure 5. Gender representation among participants

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5.1.3 Age

Participation in the study was reserved for farmers above 18 years and included various age groups. As noted in Figure 6 below, there was a representation of all age categories among the participants. The age distribution shows that more than 65% of the farmers were over 45 years old demonstrating that the majority are experienced farmers.

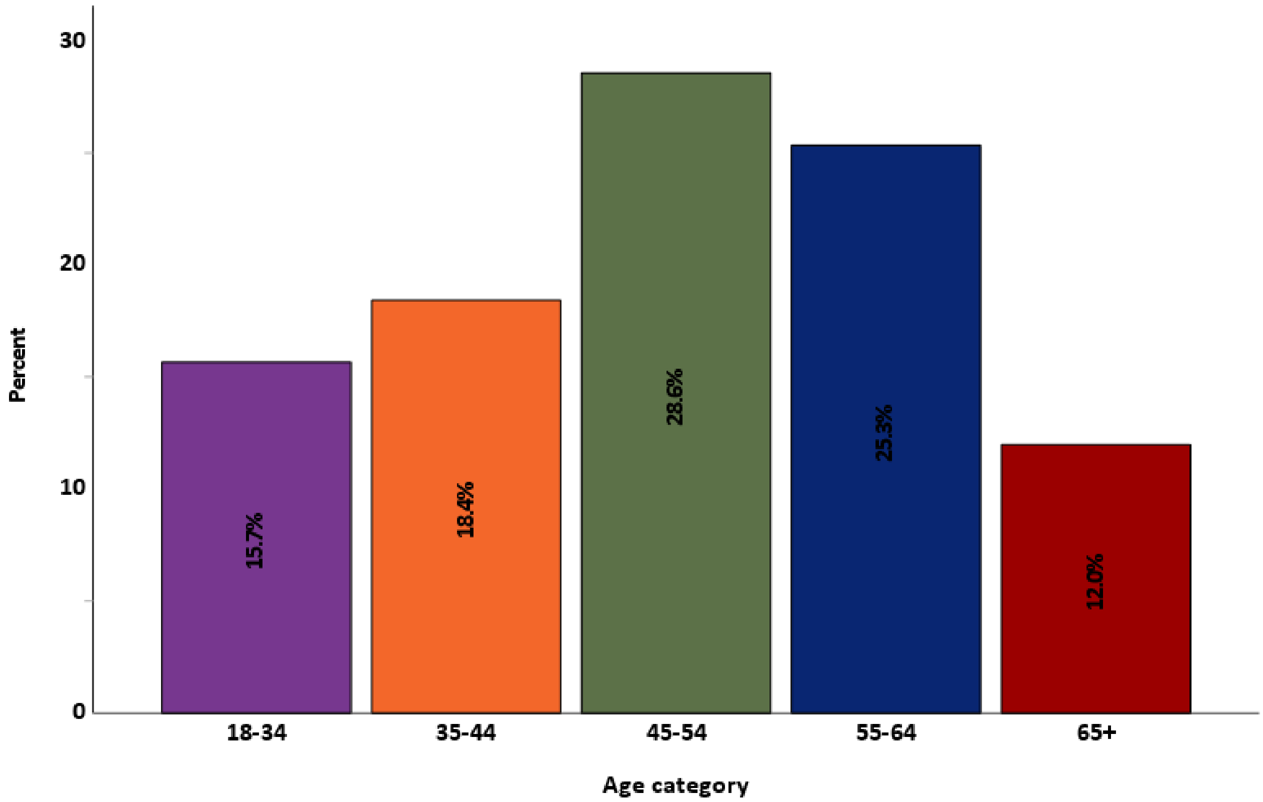

Figure 6. Age distribution of participants

5.1.4 Education

The sample comprises highly educated farmers. As illustrated in Figure 7 below, the majority of participants possess a minimum of post-secondary education or higher, with only about 6% having secondary education or less. This high literacy rate among participants can be attributed to the purposive and snowball-sampling methods employed. Consequently, many of the initially identified vineyard and olive grove farmers were educated individuals who then referred their colleagues to participate in the survey.

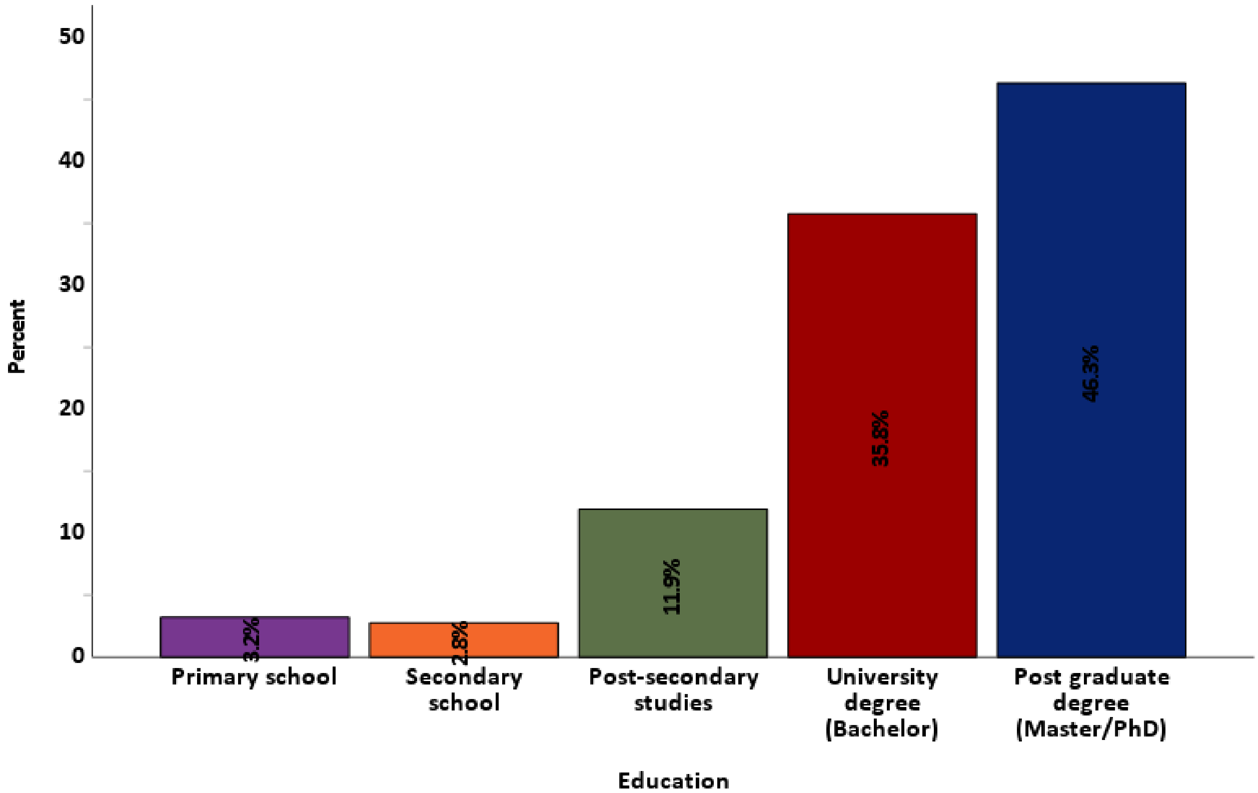

Figure 7. Educational background of participants

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5.1.5 Sector

As the NOVATERRA project focuses on finding alternatives to plant protection products in vineyards and olive groves in the EU Mediterranean area, the survey was limited to the two sectors. Out of the 354 valid responses, 77% of them were involved in vine/grape cultivation while 23% of them were involved in the cultivations. It is important to mention again that the selected alternative innovations for this study are applicable in both sectors for which reason the imbalance of the participants between the two sectors does not affect our analyses.

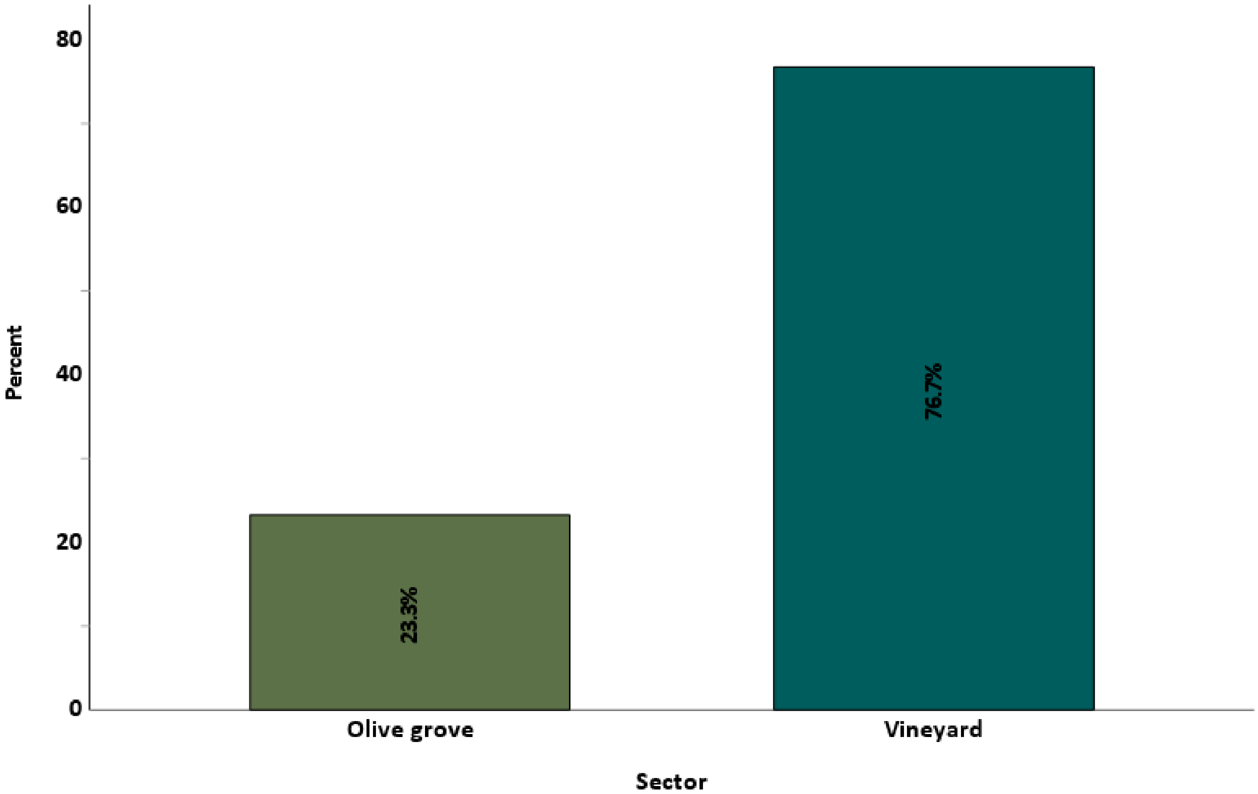

Figure 8. The representation of participants from the two sectors

Table 4. Summary of descriptive statistics of participants

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Variable	Category	Percentage
Country	Greece	8.8%
	France	8.2%
	Italy	10.2%
	Portugal	34.7%
	Spain	38.1%
Gender	Male	79.8%
	Female	20.2%
Age	18-34	15.7%
	35-44	18.4%
	45-54	28.6%
	55-64	25.3%
	65+	12.0%
Education level	Primary school	3.2%
	Secondary school	2.8%
	Post-secondary studies	11.9
	University degree (Bachelor's)	35.8%
	Postgraduate degree (Master/PhD)	46.3%
Sector of participants	Vineyard	76.7%
	Olive grove	23.3%

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5.1.6 Effectiveness of farmer's current methods

To assess farmers' beliefs regarding their existing pest control practices, they were asked to rank the effectiveness of their current methods. Figure 9 presents the mean ranks based on 354 valid responses. The distribution is positively skewed, suggesting a strong confidence in the existing pest control strategies by the majority of the farmers. However, the results also suggest room for improvement, with approximately 13% of participants rating their current methods as average or below in terms of their effectiveness in achieving pest control targets. Furthermore, even among those who consider their methods effective, only 4.5% express extreme confidence in their efficacy.

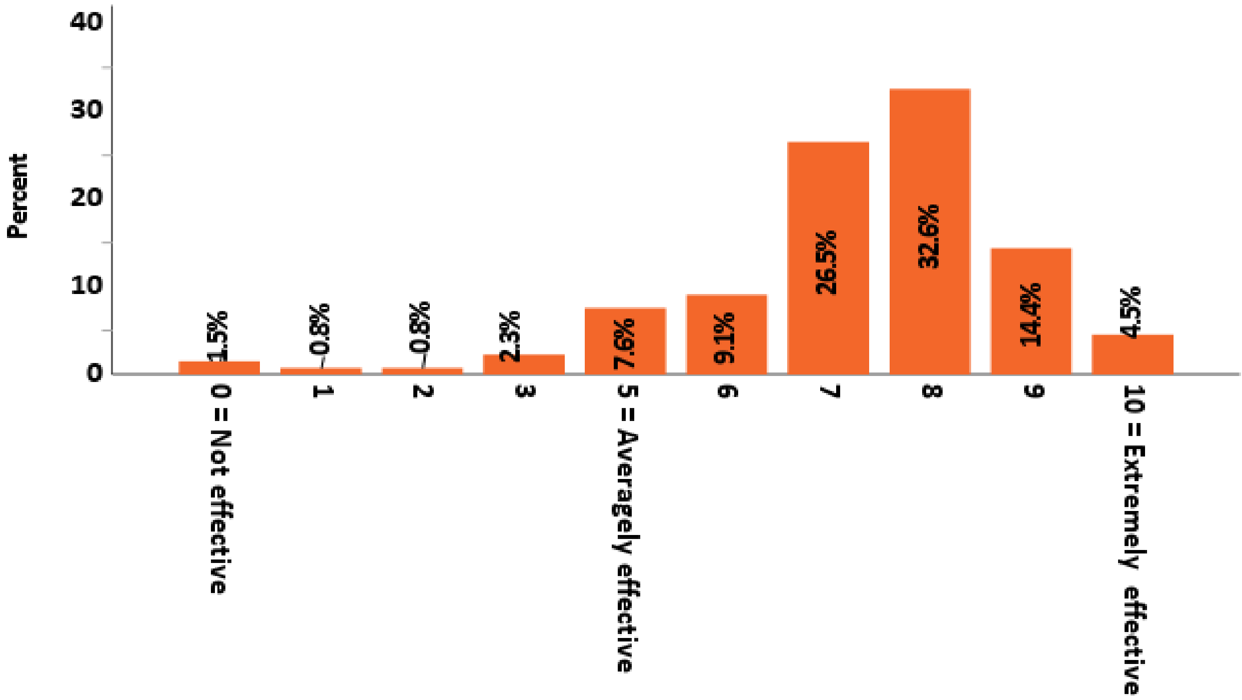

Figure 9. Mean rank of participants' effectiveness of their current method

5.1.6 Sources of trusted information

Information, as well as its source plays a crucial role in innovation adoption among farmers (Caffaro et al., 2020). According to Rogers (2003), innovation adoption begins with sharing information with potential users through two main channels: a. impersonal channel (i.e., without a direct face-to-face exchange, such as mass media) and b. personal channel (i.e., communication contacts that involve a direct face-to-face exchange). Past research has shown the mass media to be the primary source of technological awareness, while personal information sources were found to have the most critical role in technology adoption (Cavallo et al., 2014; McBride & Daberkow, 2003).

Hence, we sought to identify the most trusted sources of information among the farmers who participated in the study by asking participants to select three main sources of information that they trust most for their pest control strategies. Among the top sources of trusted information were the Technical advisors (23.2%), Research and Universities (14.7%), Technicians of Commercial input companies (13.2%)

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and Workshops, Seminars and Conferences (9.7%). The chart below in Figure 10 shows further details of the various information sources that farmers in the vineyard and olive grove sectors trust for their pest control activities.

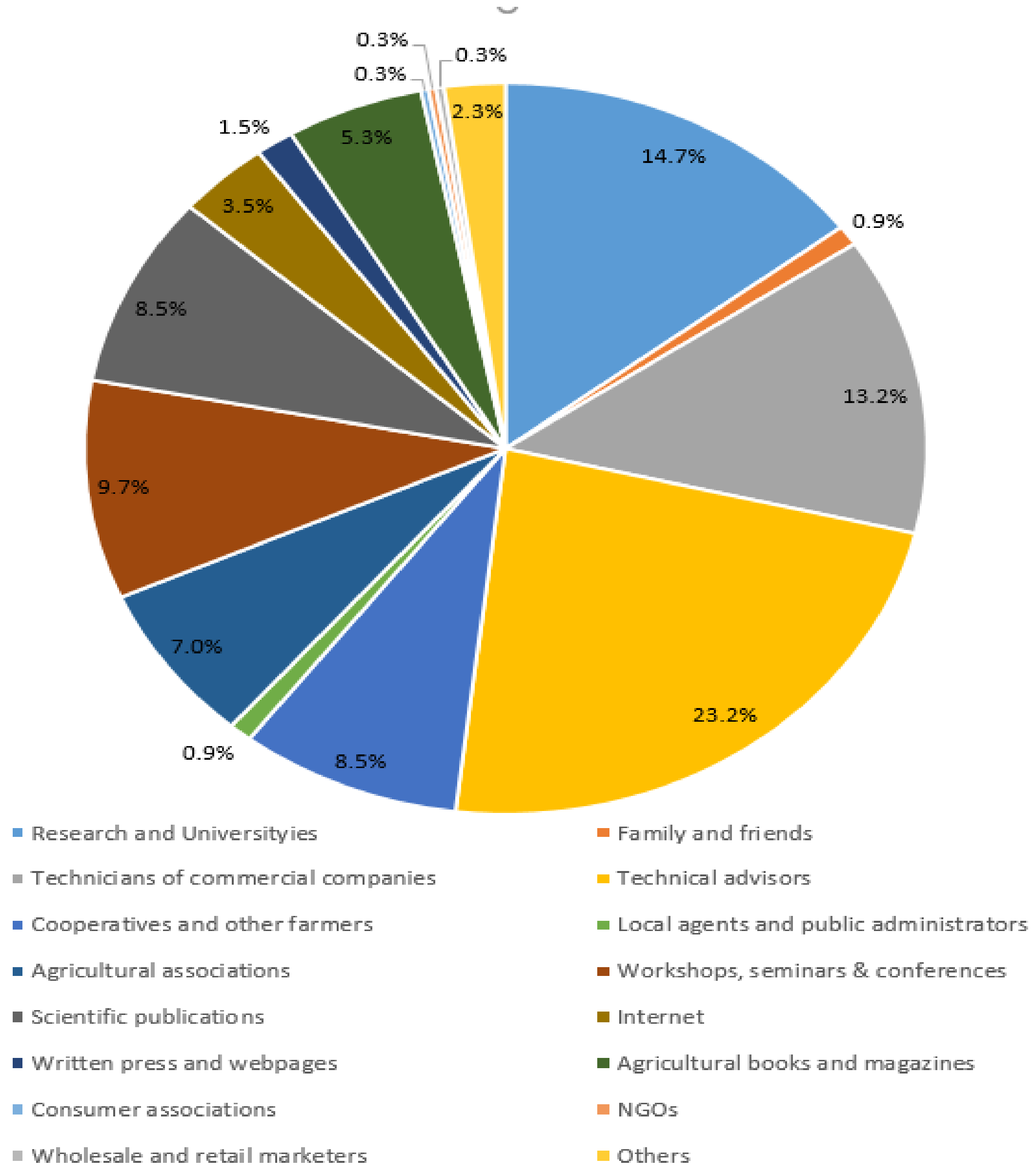

Figure 10. Sources of trusted information for pest control activities by farmers

5.2 Farmers’ willingness to adopt alternatives to contentious plant protection products

While the development of sustainable innovations such as the alternatives to PPPs is essential for driving sustainability in the agricultural sector, the adoption or diffusion of the innovations among farmers is equally important to realize the full potential of the innovations. It is for this reason that several studies try to assess innovation adoption and diffusion either ex-ante or ex-post to determine the potential or true impact of technologies developed for positive change in the agricultural sector, see (Boufous et al., 2023; Olum et al., 2020)

In most of the studies assessing the ex-ante willingness to adopt farm innovations by farmers, the willingness to pay (WTP)-which estimates the maximum amount of money or compensation a person is willing to expend to acquire a good, service, or outcome) or the willingness to accept (WTA)-which estimates the minimum amount of compensation a person is willing to accept to forgo an existing practice or method) are often used as a proxy for adoption (Olum et al., 2020). These methods often involve elicitation methods that demand the subjects to make certain monetary commitments, which are used to value their readiness to adopt a particular innovation. The monetary inducement in WTA or commitment in WTP sometimes leads to overestimation or underestimation of the true willingness to adopt certain innovations.

To assess farmers' willingness to adopt the alternative pesticide-reducing innovations, the participants were asked to indicate the percentage of their farm area on which they intend to implement each of the described innovations in Table 3. This method of elicitation not only addresses the monetary inducements or commitment in WTA and WTP but also gives farmers the chance to opt for partial adoption which is not often implemented in WTP and WTA studies. For certain innovations such as those selected for this study, farmers may be willing to adopt them on a partial scale to test their efficacy and effectiveness before a full-scale adoption. The responses for each innovation are presented in Table 5 below.

a. Smart canopy characterization: Regarding this alternative innovation, 20% of participants expressed they will not implement it on their farms, while approximately 16% are uncertain about their willingness to adopt it. Among those open to adopting this pesticide-reducing innovation, 22% are willing to implement it on a full-scale basis, and 18% are willing to implement it on up to 20% of their farm.

b. Robot (Modular-E with end-effector): For this innovation, 26% indicated they are unwilling to adopt it on their farm while 15% are uncertain. Of those who are willing to adopt this innovation, 18% opted for full-scale implementation while 17% are willing to implement it on up to 20% of their farm.

c. Bio-solutions: Only 9% of farmers are unwilling to adopt this innovation while 12% are not certain. Of those willing to adopt this innovation, 28% opted for full-scale implementation while 16% are willing to implement it on up to 20% of their farm.

d. Cover cropping with floral margins: For this alternative method, 14% are unwilling to adopt it while 12% are uncertain about its adoption or otherwise. Of the farmers who are willing to adopt this innovation in varying proportions, 24% are willing to implement it on full scale while 23 prefer to implement it on up to 20% of their farm.

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Table 5. Farmers' willingness to adopt alternative innovation

PROPORTION OF FARM AREA	Smart Canopy Characterisation	Robot (Modular-E)	Bio-solutions	Cover Cropping with Floral Margins
	PERCENTAGE WILLINGNESS TO ADOPT ALTERNATIVE INNOVATION			
None	20.1	26.5	9.6	14.2
1-20%	18.4	17.3	16.1	22.7
21-40%	10.2	11.0	13.2	9.9
41-60%	7.8	6.0	10.7	11.0
61-80&	5.3	6.0	11.1	6.0
81-100%	22.3	18.0	27.5	23.8
I don't know	15.9	15.2	11.8	12.4

The **responses from participants' willingness to adopt each alternative innovation were categorized into three main groups based on Table 5**:

No – those who are **not willing** to adopt them on any proportion of their farmland,

Yes – those that are **willing** to adopt or implement on part or full proportions of their farmland and

Uncertain *(I don't know*) – those who are **unsure** of their willingness to adopt them.

The three main groups are presented in Figure 11 below. It can be seen that overall, 64% are willing to adopt *Smart canopy characterization* either on a partial or full scale, 58% for *Robot with mowing end-effector*, 77% for *Bio-solutions*, and 73% for *Cover crops with floral margins*. Thus, in terms of the farmers' willingness to adopt each selected innovation, *Bio-solutions* attract the higher number followed by *Cover crops with floral margins, Smart canopy characterization* and *Robots with mowing end-effectors* in decreasing order.

Coincidentally, the order of the innovations, in terms of the percentage of farmers willing to adopt them aligns with the order of the initial investment cost required to implement them at the farm level (see Table 3). Per the estimates provided by partners developing the innovation, Bio-solution has the lowest cost of adoption (None), followed by Cover crop with floral margins, Smart canopy characterization and Robot with mowing end-effector. Thus, farmers' willingness to adopt the innovations is partly influenced by cost as observed by the correlation between the initial investment cost and the percentage of farmers' willingness to adopt each of the four innovations.

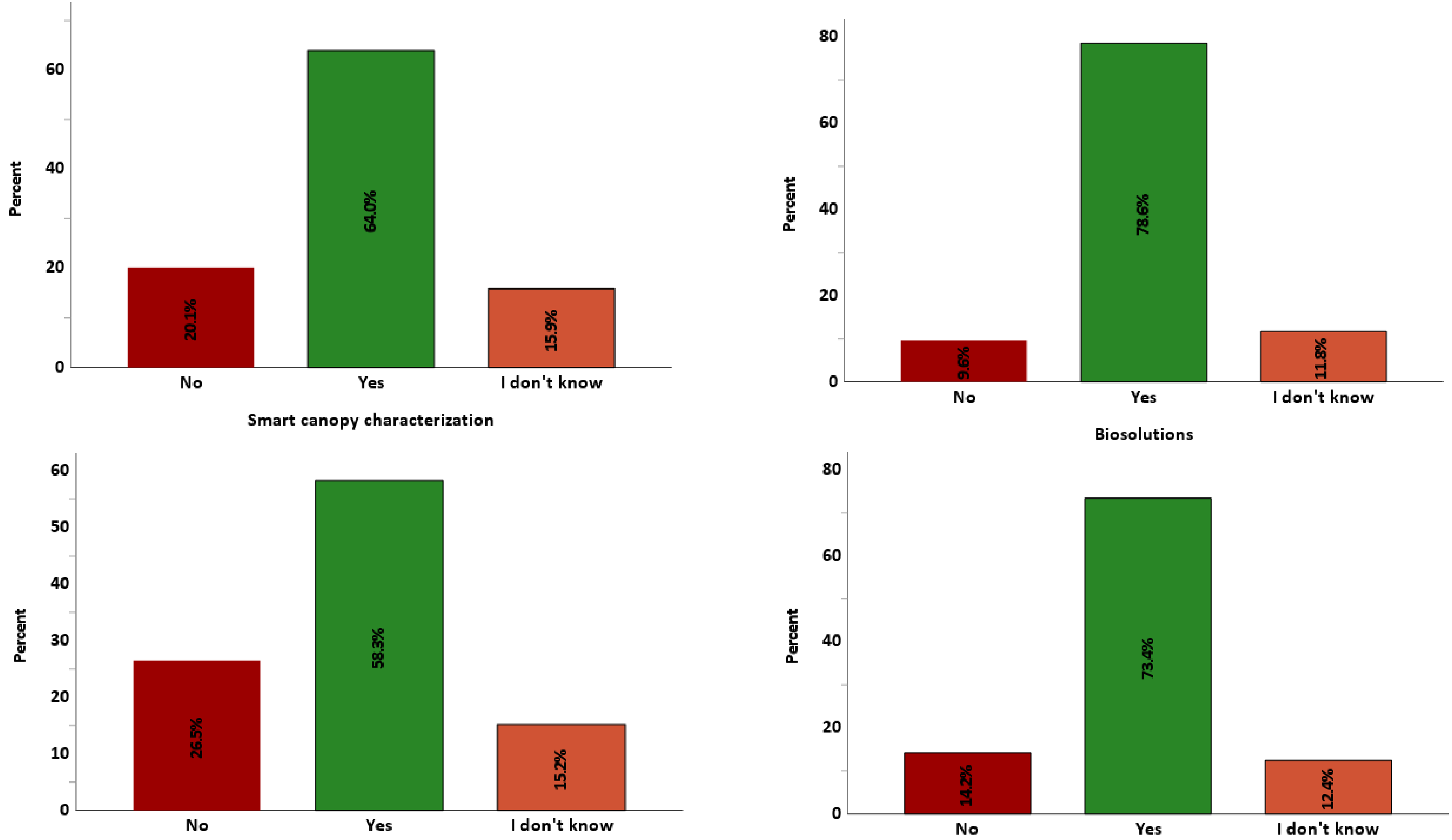

Figure 11. Farmers' willingness to adopt alternative innovations

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5.2.1 Impact of consumers' willingness to pay on the adoption decision of farmers

In Table 6 below, we juxtapose the influence of consumers' willingness to pay more as an incentive on farmers' willingness to adopt alternative innovations with the previous responses in Table 5.

Firstly, the information on consumers' willingness to pay more significantly influenced the participants' responses regarding their willingness to adopt decisions across all four innovations. Specifically, the percentage of participants who were willing to adopt each innovation on varying proportions of their farmland, those who were unwilling to adopt (except for the Robot with a mowing end-effector), and those who were uncertain (i.e., "I don't know") significantly changed with the information that consumers are willing to pay more for products from alternative innovations that reduce pesticide use, as presented in part b of Table 6.

Secondly, for all four innovations except for *Robot with a mowing end-effector,* which remained unchanged, the percentage of participants willing to adopt them increased slightly when farmers were presented with the result that consumers are willing to pay more. For instance, the percentage willing to adopt moved from 64% to 65% for *Smart canopy characterization*, from 78% to 82% for *Bio-solutions* and from 73% to 76% for *Cover crops with floral margins*. The increases in percentage willingness to adopt were statistically significant for *Bio-solutions* and *Cover crops with floral margin* but not for the Smart canopy characterization. Further observation reveals that the increases in the percentages of participants willing to adopt the three alternative innovations were a result of the decrease in the number of those who were uncertain (i.e. "I don't know" responses), implying that part of the uncertainty responses are attributable to the cost or financial implications of adopting the alternative innovations.

Table 6. Farmers' willingness to adopt alternative innovations

	a. PERCENTAGE WILLINGNESS TO ADOPT ALTERNATIVE INNOVATION			
PROPORTION OF FARM AREA	**Smart Canopy Characterisation**	**Robot (Modular-E)**	**Bio-solutions**	**Cover Cropping with Floral Margins**
None	20.1	26.5	9.6	14.2
1-20%	18.4	17.3	16.1	22.7
21-40%	10.2	11.0	13.2	9.9
41-60%	7.8	6.0	10.7	11.0
61-80&	5.3	6.0	11.1	6.0
81-100%	22.3	18.0	27.5	23.8
I don't know	15.9	15.2	11.8	12.4
	b. WITH CONSUMER WTP INFORMATION			
None	22.4	26.5	12.7	15.9
1-20%	16.7	16.3	15.9	18.8
21-40%	9.0	9.0	12.2	10.6
41-60%	9.0	6.9	9.4	11.0
61-80&	5.3	4.5	24.5	19.2
81-100%	24.5	20.8	19.6	16.3
I don't know	13.1	15.9	5.7	8.2

NB: **Part a** is the same as in 5 above and **part b** is the percentage adoption with consumer information

5.2.2 Reasons behind not willing to adopt

The reasons behind the unwillingness of participants to adopt alternative innovations were investigated. Economic factors, primarily the perceived high cost, emerged as the primary concern for three of the selected alternative innovations, excluding Bio-solution. Close to 50% of those unwilling to adopt these three alternatives cited the cost as the main deterrent, underscoring the pivotal role of initial investment costs in farmers' decision-making within the vineyard and olive grove sectors.

Beyond economic factors, the suitability of the innovations ranked second for three out of the four selected options, with Bio-solutions being the exception where it is the primary reason. Among farmers who are hesitant to adopt Bio-solutions as an alternative to controversial plant protection products, 40% cited concerns about its suitability for their specific farming conditions.

The reasons given by participants for not adopting alternative innovations included difficulties in implementation, insufficient subsidies, and an excessive perceived workload that overshadowed the potential benefits. Only a small number of respondents cited a lack of interest as the sole reason for their reluctance. These reasons were considered the most sincere of all the explanations provided by participants regarding their hesitation to adopt the selected innovations.

We consider all reasons listed in Table 7, with the exception of those labelled "just not interested in any innovation," to be external factors that can be addressed to encourage the adoption of alternative innovations. For farmers without a reason, a shift in attitude may be necessary, which can often be achieved through information or strict regulations. Fortunately, these farmers represent less than 5% of those unwilling to adopt alternative innovations, indicating a positive overall outlook for the adoption of the chosen alternative innovations among vineyard and olive grove farmers.

Table 7. Reasons for unwillingness to adopt alternative innovations

Reason	Smart canopy characterization	Robot with mowing end-effector	Bio-solution	Cover crop with floral margins
Not suitable for my farm	23%	31%	40%	17%
Economic considerations (too expensive)	42%	49%	15%	51%
Difficult to implement at the farm	8%	10%	20%	10%
Absence of subsidies or other economic incentives	11%	3%	5%	7%
Involves too much work to get few results	12%	5%	15%	12%
Just not interested in any innovation	0%	2%	5%	2%
Regulatory framework will it difficult	2%	0%	0%	-
Needs user training	3%	0%	0%	-

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5.3 Predicting farmers’ adoption intentions

The preceding sections offer a significant overview of farmers' willingness to adopt alternatives to contentious plant protection products. While these responses provide insight into the potential acceptance or rejection of the four selected innovations tested in this study, they alone are insufficient for predicting farmers' likelihood of adopting alternative pesticide-reducing innovations being proposed under the NOVATERRA project. In light of this, we have opted to utilize the theory of planned behaviour (TPB), a well-established and widely embraced theoretical framework, as detailed in the methodology section, to predict and understand farmers' intentions to adopt these innovative alternatives.. Using our extended TPB model, we evaluated farmers' adoption intentions based on five main factors: attitude (ATD), subjective norm (SN), perceived behavioural control (PBC), perceived effectiveness of existing methods (PE), and familiarity with sustainable innovation (FEST).

As stated in the method section, the Smart-PLS© software was used for the analysis because it offers methodological approaches specifically designed for assessing complex causal relationships among various latent variables.

To ensure the overall reliability and validity of the items (statements) in measuring their respective constructs, the Factor Loadings (Table A1), Average Variance Extracted (AVE), Cronbach-Alpha and Composite Reliability (Table A2), multicollinearity and discriminant validity (Table A4) were calculated to check for internal consistency. The validation using these measurements is crucial, as highlighted in the study by Hair et al., (2021) This is important because if the model fails to fit the data, the resulting estimates will lose their significance leading to doubtful conclusions.

All the measurement indicators confirmed the reliability and validity of the items and constructs used in our study. For instance, the factor loadings that reflect the extent to which each observed statement or item contributes to the measurement of its corresponding latent construct were all higher than 0.70 except INT3, INT4, and PE4 in Table 2. Higher item loadings indicate a stronger relationship between the item and the construct and usually a value of 0.7 is recommended (Leguina, 2015). Therefore, INT3, INT4 and PE4 were dropped from the analysis with the remaining items having the least factor loading value of 0.72 (see Table A1).

Again, for the AVE reliability test, a value greater than 0.5 is suggested to ensure that the proposed items accurately measure the intended constructs (Cheung et al., 2023). Our test produced values higher than 0.5 as recorded in Table A2. Furthermore, the internal construct consistency, which assesses the extent to which the items in the measurement instrument are consistent with each other and that they are measuring the same concept was checked with the Cronbach-Alpha. The results, reported in Table A2 show that the Cronbach-Alpha of all the items are greater than the 0.70 threshold. This indicates a high level of internal consistency of constructs within the proposed TPB model

Finally, multicollinearity (i.e. a phenomenon where the constructs are highly correlated) and discriminant validity (i.e. the extent to which two constructs are distinct and not measuring the same underlying concept or variable) checks were conducted using the variance in inflation factor(VIF) in Table A3 and the Heterotrait-Monotrait Ratio (HTMT) in Table A4 respectively. The VIF values for all the constructs were below 3.0 suggesting the absence of multicollinearity or common method bias (Garmendia-Lemus et al., 2024). The HTMT values were also found to be less than 0.85 suggesting a distinctiveness among all the constructs of our model (Roemer et al., 2021).

5.3.1 Structural Equation Model results

After confirming the reliability and validity of all constructs and measurement items, we proceeded to test the hypothesized relationships within the model by analysing the structural equation models (SEMs). Initially, we examined the original TPB model, depicted in Figure 1, which includes the direct effects of Attitudes, Subjective Norms, and Perceived Behavioural Control on farmers' intentions to adopt alternative pesticide-reducing innovations. This allowed us to assess the individual contributions of these variables without the influence of additional mediators or constructs. The results of the original model (not detailed here) confirmed that Attitudes, Subjective Norms, and Perceived Behavioural Control all positively influence the adoption intentions of vineyard and olive grove farmers towards pesticide-reducing innovations. Although our primary objective is to extend the TPB model to incorporate relevant factors likely to affect adoption intentions, the validity of the original TPB provides a solid foundation for our extended model.

The extended TPB model provides deeper insights into the underlying mechanisms behind the relationships of the original TPB model and the specific roles of Perceived cost, Perceived effectiveness of existing practice, and Familiarity with sustainable innovation as an additional construct. All the additional constructs in the extended TPB are hypothesized to directly influence farmers' intentions to adopt pesticide-reducing innovations without any mediators.

The R^2 value, which measures goodness of fit, was 0.44, indicating that the constructs explain 44 % of the variation in farmers' adoption intentions. Apart from the R^2 value, all the other goodness of fit indices (see Appendix) showed that the structural model fitted the data well.

The results obtained in the form of the standardized path coefficients (β) and their significance in the structural equation modelling are presented in Table 8 and Figure 12 below.

H1-H3: Farmers' ATT, PBC and SN toward alternatives to PPPs bolster their Intention (INT) to adopt these innovations

The hypothesized path (H1, β = 0.623; *Attitudes → Intentions*) was found to be positive and statistically significant, indicating that a more positive attitude leads to higher adoption intention of farmers towards using pesticide-reducing innovations

Similarly, the hypothesized paths (H2, β = 0.008; *Perceived Behavioural Control → Intentions* and H3, β = 0.047; *Subjective Norm → Intentions*) were found to be positive indicating that higher perceived behavioural control and subjective norms lead to higher adoption intentions among farmers. However, these two paths had a lower influence on adoption intentions and were statistically insignificant according to their P values.

H4: The perceived cost associated with alternatives to PPPs will bolster farmers' intention (INT) to adopt pesticide–reducing innovations

This hypothesized path (H4, β = -0.380; Perceived cost → Intentions) was found to be negative and highly significant. This means that the perceived cost associated with pesticide-reducing innovations leads to lower intentions to adopt these innovations.

H5: Perceived effectiveness of existing methods of pest control among farmers impacts the intention(INT) to adopt pesticide-reducing innovations

Similar to hypothesis 4, the hypothesized path (H5, β = -0.191; Perceived effectiveness of existing methods → Intentions) was found to be negative and statistically significant implying that farmers perceived effectiveness of their existing pest control methods lower their intentions to adopt alternative pesticide-reducing innovation

H6: Farmers' familiarity with sustainable innovations bolsters their Intention(INT) to adopt pesticide-reducing innovation.

Lastly, the hypothesized path (H6, β = 0.106; Farmers' familiarity with alternatives to contentious PPPs → Intentions) was found to be positive and fairly significant. This thus, suggests that farmers' familiarity with the four selected innovations leads to higher intentions to adopt them.

Table 8. Results of the hypotheses testing

Path coefficients - Mean, STDEV, T values, p values   Zoom (85%)   Copy to Excel   Copy to R

	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values
Attitude -> Intention to Adopt Pesticide Reducing Innovations	0.623	0.622	0.081	7.649	0.000
Familiarity with Sustainable Innovations/Solutions -> Intention to Adopt Pesticide Reducing Innovations	0.106	0.107	0.058	1.816	0.035
Perceived Behavioural Control -> Intention to Adopt Pesticide Reducing Innovations	0.008	0.006	0.082	0.099	0.461
Perceived Cost -> Intention to Adopt Pesticide Reducing Innovations	-0.380	-0.378	0.085	4.493	0.000
Perceived Effectiveness of Existing Practice -> Intention to Adopt Pesticide Reducing Innovations	-0.191	-0.191	0.057	3.356	0.000
Subjective Norms -> Intention to Adopt Pesticide Reducing Innovations	0.047	0.047	0.076	0.613	0.270

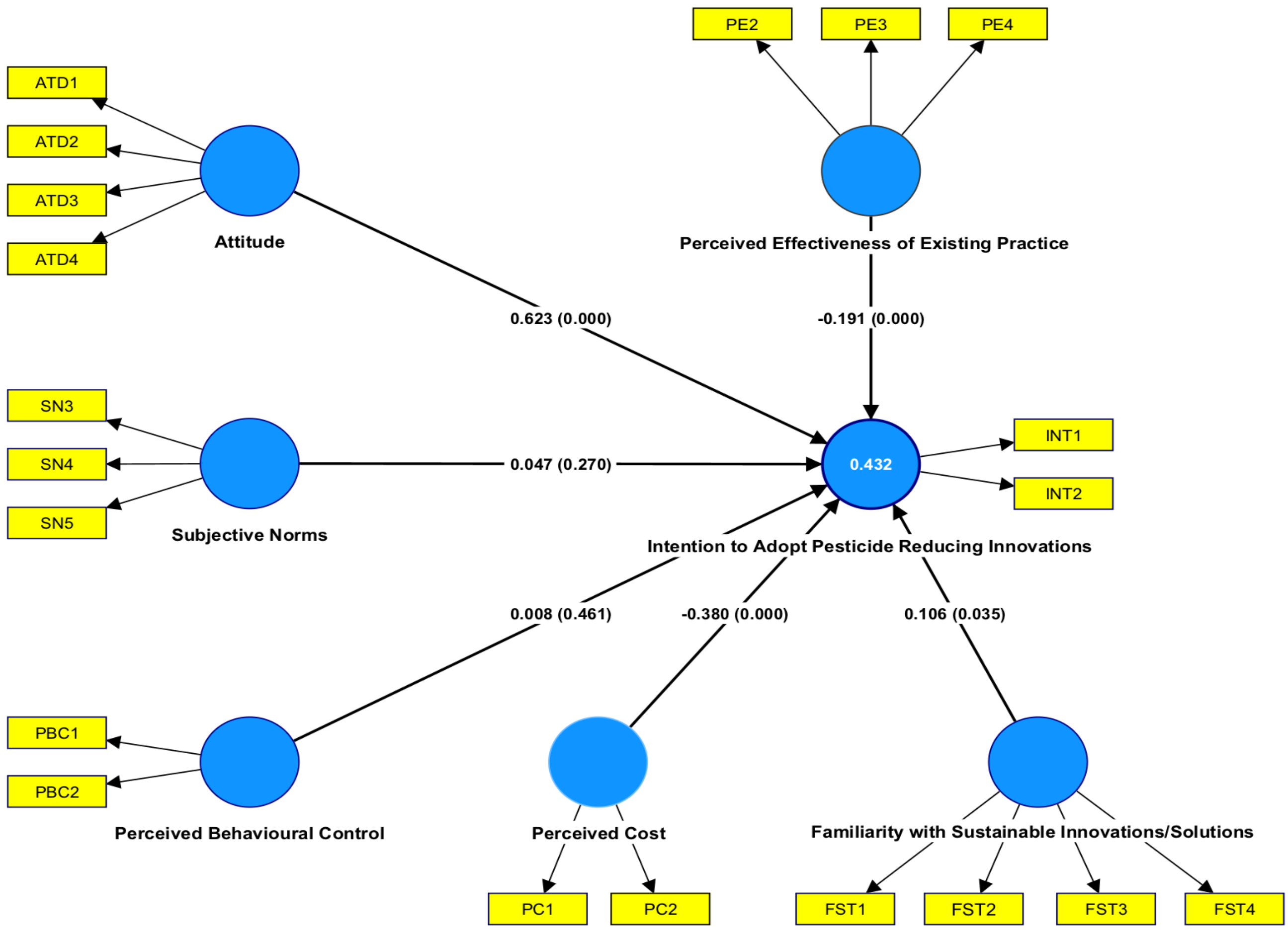

Figure 12. Graphical representation of path coefficient results from the SEM

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5.3.2 Interpretation and implication of the TPB results

The SEM results of the extended TPB, as presented in Table 8 and Figure 12, show that four of our six constructs have a direct influence on farmers' intentions to adopt alternative pesticide-reducing innovations. Of the four constructs that have a direct effect on the adoption intentions, attitude has the highest loading (0.623) suggesting that farmers' own judgements are crucial in the adoption intention towards alternative pesticide reduction innovations in the vineyard and olive grove sectors. Convincing farmers is crucial for the successful implementation of alternative pesticide-reducing innovations in the Mediterranean vine and olive sectors. To encourage farmers to adopt these alternatives, it is essential to address factors that contribute to positive attitudes, such as providing information on benefits, addressing concerns about efficacy, sustainability, or costs. By doing so, the vine and olive sectors can enhance farmers' overall attitude towards alternatives to PPPs, leading to increased adoption intentions and ultimately higher adoption rates.

Farmers' adoption intentions of pesticide-reducing innovations are heavily influenced by not just their attitude, but also by the perceived cost associated with these innovations. We observed that the negative and significant impact of the perceived cost emphasizes the financial considerations and risk perceptions that farmers take into account when making decisions about adopting pesticide-reducing innovations. This finding confirms the findings under section 3.4, where the percentage of farmers who were willing to adopt the four selected case study innovations was strongly correlated with the investment cost of the innovations. Farmers are keen to know how the use of alternatives to contentious PPPs would be effective in controlling pests and diseases, improve yield and ultimately, improve their financial gains. Promoting the adoption of sustainable agricultural innovations necessitates addressing concerns and demonstrating economic feasibility. This can be achieved through various strategies such as conducting field trials and farm demonstrations, providing cost-benefit analyses, offering education programs and workshops, sharing case studies and success stories as noted by (Garmendia-Lemus et al., 2024).

The third significant construct was the perceived effectiveness of existing methods, which has a direct negative influence on the adoption intentions of farmers. This research has several noteworthy implications. Initially, it underscores the propensity of participating farmers to adhere to their conventional or customary pest management methods, which they believe to be effective. As a result, farmers who hold the view that their prevailing pest management techniques are sufficient may be less inclined to adopt innovations that decrease pesticide utilization. Moreover, this finding accentuates the significance of providing precise information and education about the benefits and efficacy of the alternative innovations endorsed by the NOVATERRA project. So far, it is crucial for farmers to thoroughly comprehend the benefits of the alternatives to PPPs, in order to encourage them to switch from their current methods.

The most critical element that directly enhances the adoption intentions of farmers is their familiarity with sustainable innovations. This implies that farmers' understanding of sustainable innovations is crucial in shaping their awareness, knowledge, and confidence, and might help reduce the obstacles to adoption. Thus, promoting alternatives to controversial PPPs necessitates providing farmers with more education and information to increase their acceptance.

It is worth mentioning that in our extended TPB model, both the subjective norms and perceived behavioural control were not statistically significant in influencing the adoption intentions of farmers. This may be due to contextual factors or sample characteristics. In terms of contextual factors, SN and PBC may vary depending on the study objective and the farmers involved. In this study, where we predict the adoption intention of vineyard and olive grove farmers towards alternative innovations, the SN (i.e. perceptions of social pressure or expectations from others) may be less important if farmers operate relatively independently or if there is a diversity of practices within the farming sector. Also, for this topic, the PBC (i.e. perceptions of the ease or difficulty of adopting the innovation) may not matter if farmers feel confident in their ability to overcome any obstacles or barriers to adoption. Considering the educational background of the farmers in this study (see section on the sociodemographic characteristics of participants) we are tempted to say the two constructs may be contextually and less important due to the characteristics of the sample. Therefore, further research and analysis may be needed to better understand the underlying reasons for these findings and to identify additional factors that shape adoption intentions among farmers.

5.4 Web-based tool to predict the adoption intentions

It is important to note that the TPB is a framework used to understand and predict human behaviour, about goal-directed actions. Hence, using the results of the extended TPB above as the baseline, one can systematically predict the adoption intention of farmers towards pesticide-reducing innovations. This is exactly what we executed in our web-based tool as summarized as follows

- Through our extended TPB with obtained six constructs that directly predict adoption intentions i.e., the original constructs (Attitude-ATD, the Subjective Norm –SN and the Perceived Behavioural Control-PBC) in addition to extended constructs (Perceived Cost-PC, The Perceived Effectiveness of Existing Practice-PE and Familiarity with Sustainable Innovations-FST). Note that for this predictive tool, all constructs are assumed to influence adoption intentions directly without any mediators.
- The six constructs were measured with 18 measurement indicators (statements) i.e., ATD (4), SN(3), PBC(2), PC(2), PE (3) and FST(4) using a seven-point Likert scale, ranging from 1 (strongly disagree) to 7 (strongly agree).
- To create the predictive tool, the results obtained from the 354 respondents were used as the reference/baseline. Thus, using the mean ranks generated by the 354 participants for each construct and the weighted average based on the measurement indicators of each construct, we computed the **Baseline Mean Rank Coefficient (BMRC).** The BMRC gives the minimum rank coefficient that is required to qualify a user as having an intention to adopt alternative pesticide-reducing innovations and it is computed from Table 9 below.

Table 9. Descriptive statistics of TPB constructs from the Likert Scale ranking

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Attitude	354	2	7	5.59	1.171
PerceivedBehavioralControl	354	1	7	4.86	1.812
SubjectiveNorms	354	2	7	5.35	1.396
PerceivedEffectiveness	354	1	7	3.09	1.733
PerceivedCost	354	1	7	4.58	1.923
Familiarity	354	1	7	4.48	1.786
Intention	354	1	7	6.00	1.386
Valid N (listwise)	354				

- The computed BMRC was found to be approximately 1.23. This becomes the reference value, with which new respondents' mean rank coefficient (calculated using the same method) are compared. Thus, the BMRC is the minimum rank coefficient that one needs to attain to be seen as having adoption intentions towards pesticide-reducing innovations after ranking the 18 measuring indicators of the 6 constructs.
- Afterward, we developed a web application utilizing SpreadsheetWeb by incorporating the 18 measurement indicators across the 6 constructs that are utilized to calculate the BMRC. Users/farmers whose adoption intentions are to be predicted can access the predictive tool via this link. The instructions for navigating through the tool are given on the introductory page. To successfully navigate through the entire indicators, it is required that responses be provided for each measuring indicator. Images 1 and 2 below show an overview of the user interface of the predictive tool.

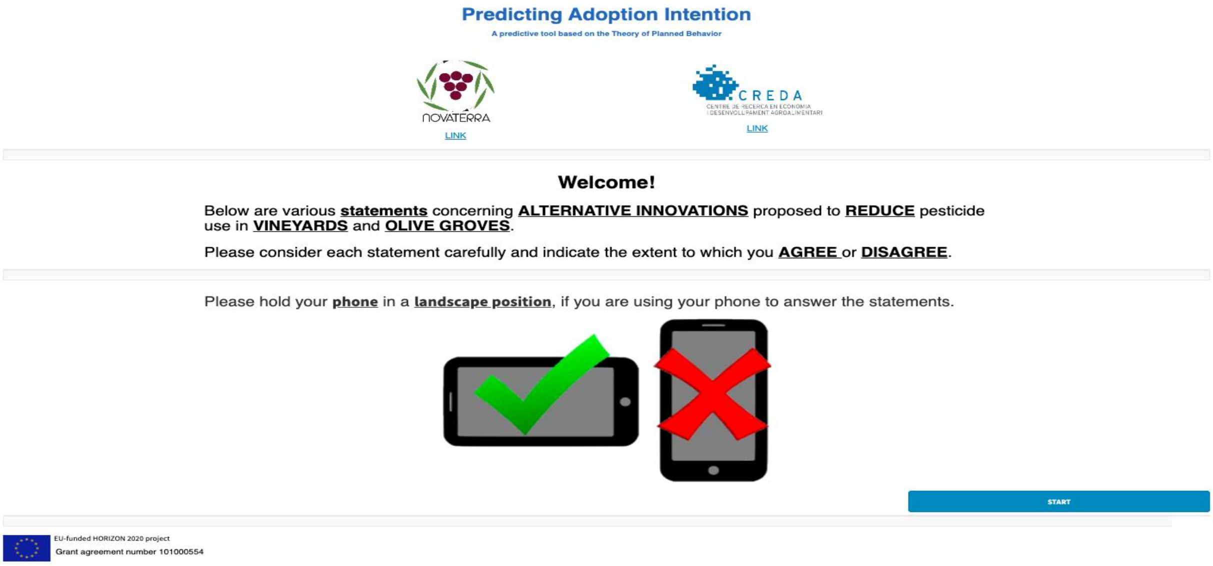

Image 1. The Introduction page of the predictive web tool

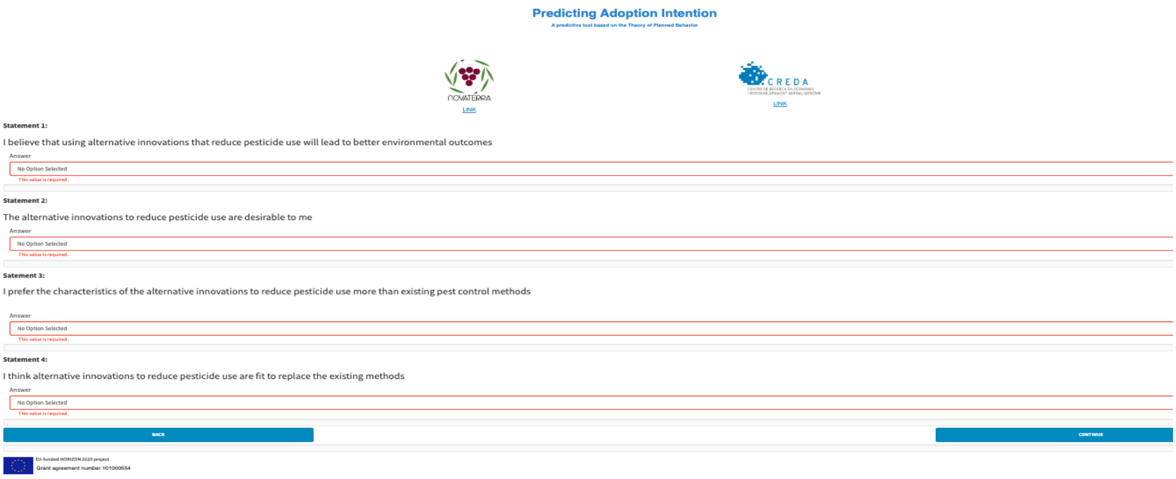

Image 2. Sample page showing response fields of the measuring indicators

- After responding to all the measuring indicators, an opportunity is given for an optional comment about the alternative pesticide-reducing innovations as shown below in Image 3.

Image 3: Application's comment section

- By selecting **"Results"**, the user's adoption intention is predicted and displayed based on the responses provided. The prediction is done by comparing the users' mean rank coefficients (MRC) to the BMRC. Consequently, the tool predicts whether the subject has high, moderate, low or no intention to adopt alternative pesticide-reducing innovations. In addition, a graphical explanation of the results in terms of the boundaries of the possible outcomes of the prediction is displayed with the results as shown in Image 4 below.

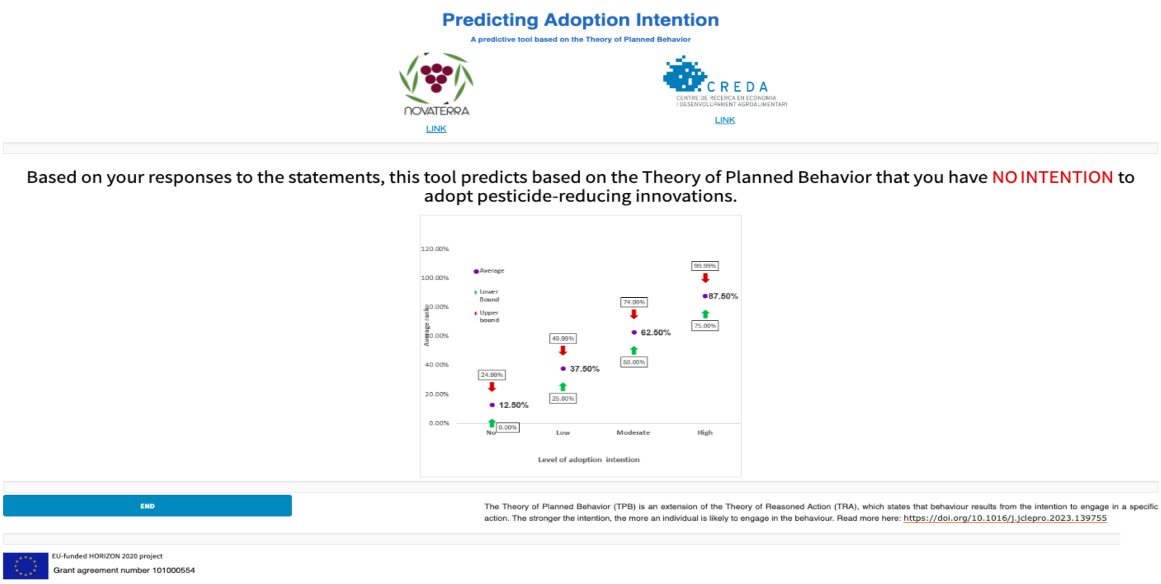

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Image 4: Sample results from the predictive tool

Interpretation of the results of the predictive web-based tool

- On the results page, users can see their likelihood to adopt alternative pesticide-reducing innovations that are predicted through their adoption intention according to their responses to the measurement indicators. Based on the responses to the measurement indicators, their MRC is computed and compared with the BMRC (1.23) to generate the results of their adoption intention. The level of intention can be High, Moderate, Low or None with the definition of the boundaries as follows:

    1. *<u>HIGH INTENTION</u>*: When computed MRC greater than 2.5 or when the MRC shows a rank agreement level of more than 75%.
    2. *<u>MODERATE INTENTION</u>*: When the computed MRC is between 1.80 and 2.49 or when the MRC shows a rank agreement level between 50% and 74.99%.
    3. *<u>LOW INTENTION</u>*: When the computed MRC falls between 1.23 and 1.79 or when the MRC shows a rank agreement level between 25% and 49.99%.
    4. *<u>NO INTENTION</u>*: When the computed MRC falls below 1.23 or shows a rank agreement level between 0% and 24.99%.

- The maximum MRC attainable is 3.19. This is achieved when a user ***strongly agrees*** to all the measuring indicators of constructs that have a positive influence on adoption intentions i.e. Attitude, Subjective Norms, Perceived Behavioural Control and Familiarity with Sustainable Innovations but ***strongly disagrees*** with indicators of the constructs that have a negative influence on adoption intentions i.e. of Perceived Cost and Perceived Effectiveness of existing Practice.
- On the contrary, the minimum MRC attainable is -1.69 and this is obtained when the preceding rank agreements are completely reversed.

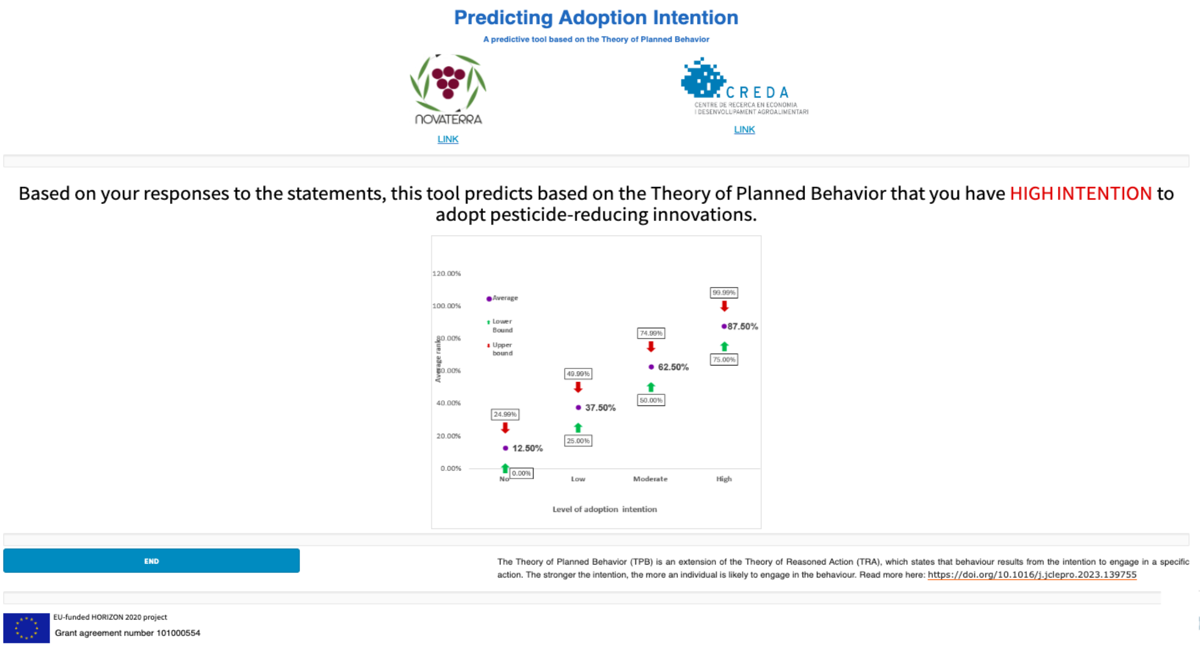

Image 5: Sample results of the predictive tool that shows high intention to adopt

ACCESS THE TOOL VIA THE LINK BELOW:

[WEB-BASED TOOL THAT PREDICTS ADOPTION INTENTION OF FARMERS BASED ON THE THEORY OF PLANNED BEHAVIOUR]

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NOVATERRA : Integrated Novel Strategies for Reducing the Use and Impact of Pesticides, Towards Sustainable Mediterranean Vineyards and Olive Groves

6.0 Summary and conclusions

This report addresses Deliverable 5.1 of the NOVATERRA project, focusing on stakeholders' acceptance of alternatives to contentious plant protection products. We utilized semi-structured interviews and structured surveys with stakeholders and farmers, respectively, to achieve the objectives of the deliverable. By employing various survey methods, we assessed farmers' willingness to adopt pesticide-reducing innovations in Mediterranean vineyards and olive groves, along with the factors influencing their adoption intentions.

Our research unveils that a significant number of **farmers are open to adopt** the four chosen alternative pesticide-limiting advancements, albeit to varying extents. It is worth noting that farmers' inclination to adopt these innovations is largely influenced by the **initial investments** required. In general, farmers show greater interest in innovations that have lower investment costs. In order to delve further into this observation, we utilized the extended Theory of Planned Behaviour (TPB), a robust model that is grounded in well-established theoretical principles.

Our research uncovered four critical elements—attitude, perceived costs, belief in the effectiveness of current pest management techniques, and familiarity with sustainable practices—that greatly influence farmers' intentions to adopt. The findings emphasize the crucial part that **farmers' own assessments**, **perceptions of cost, beliefs about effectiveness, and familiarity** with **sustainable alternatives** play in determining their adoption choices.

In contrast to the theory of planned behaviour (TPB), subjective norms and perceived behavioural control, two key elements in TPB, were found to have non-significant influence on farmers' intention to adopt alternatives to contentious plant protection products (PPPs). This indicates that social pressures or ease/difficulty perceptions may not have a significant impact on the adoption of these alternatives. Rather, it seems that **individual attitudes and cost-effectiveness perceptions play a more prominent role** in influencing vineyard and olive grove farmers' adoption decisions.

The study's results indicate that interventions aimed at promoting the adoption of pesticide-reducing innovations should address factors such as **attitudes, cost perceptions, education, and the advantages of alternative practices**. To achieve this goal, it is recommended to implement strategies that enhance **positive attitudes** towards these innovations, subsidize the **investment costs**, and **educate** farmers on the **effectiveness** of such alternatives.

Finally, based on the study results, we developed a web-based tool capable of predicting farmers' adoption intentions. The tool utilizes the significant constructs identified in the study to predict the adoption intentions, offering valuable insights and decision-making support for farmers, agricultural advisors, policymakers, and other stakeholders invested in promoting sustainable agricultural practices in the vineyard and olive grove sectors.

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8.0 Annexes

Table A1. Indicator of reliability statements measuring the constructs

Outer loadings - Matrix

	Attitude	Familiarity with Sustainable Innovations/Solutions	Intention to Adopt Pesticide Reducing Innovations	Perceived Behavioural Control	Perceived Cost	Perceived Effectiveness of Existing Practice	Subjective Norms
ATD1	0.749						
ATD2	0.724						
ATD3	0.824						
ATD4	0.752						
FST1		0.820					
FST2		0.781					
FST3		0.805					
FST4		0.809					
INT1			0.955				
INT2			0.955				
PBC1				0.899			
PBC2				0.899			
PC1					0.955		
PC2					0.955		
PE2						0.804	
PE3						0.931	
PE4						0.939	
SN3							0.856
SN4							0.836
SN5							0.720

Table A2. Test for reliability and validity of constructs

Construct reliability and validity - Overview

	Cronbach's alpha	Composite reliability (rho_a)	Composite reliability (rho_c)	Average variance extracted (AVE)
Attitude	0.760	0.763	0.848	0.582
Familiarity with Sustainable Innovations/Solutions	0.818	0.818	0.880	0.647
Intention to Adopt Pesticide Reducing Innovations	0.903	0.903	0.954	0.911
Perceived Behavioural Control	0.762	0.762	0.894	0.808
Perceived Cost	0.904	0.904	0.954	0.912
Perceived Effectiveness of Existing Practice	0.871	0.882	0.922	0.798
Subjective Norms	0.728	0.739	0.847	0.650

Note: 1-3.00: Low; 3.01-5.00: Moderate; 5.01 – 7.00: High

Table A3. Test for multicollinearity

Collinearity statistics (VIF) - Inner model - List

	VIF
Attitude -> Intention to Adopt Pesticide Reducing Innovations	2.032
Familiarity with Sustainable Innovations/Solutions -> Intention to Adopt Pesticide Reducing Innovations	1.483
Perceived Behavioural Control -> Intention to Adopt Pesticide Reducing Innovations	2.531
Perceived Cost -> Intention to Adopt Pesticide Reducing Innovations	2.851
Perceived Effectiveness of Existing Practice -> Intention to Adopt Pesticide Reducing Innovations	1.575
Subjective Norms -> Intention to Adopt Pesticide Reducing Innovations	2.323

Table A4. Results of Discriminant validity test

Discriminant validity - Heterotrait-monotrait ratio (HTMT) - Matrix

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	Attitude	Familiarity with Sustainable Innovations/Solutions	Intention to Adopt Pesticide Reducing Innovations	Perceived Behavioural Control	Perceived Cost	Perceived Effectiveness of Existing Practice	Subjective Norms
Attitude							
Familiarity with Sustainable Innovations/Solutions	0.570						
Intention to Adopt Pesticide Reducing Innovations	0.723	0.333					
Perceived Behavioural Control	0.740	0.520	0.289				
Perceived Cost	0.595	0.498	0.110	0.840			
Perceived Effectiveness of Existing Practice	0.656	0.302	0.439	0.603	0.510		
Subjective Norms	0.841	0.713	0.414	0.791	0.707	0.570	

Table A5. Results of Goodness of Fit Tests

Model fit

Zoom (

	Saturated model	Estimated model
SRMR	0.095	0.095
d_ULS	1.884	1.884
d_G	0.724	0.724
Chi-square	1,494.359	1,494.359
NFI	0.687	0.687

R-square - Overview

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	R-square	R-square adjusted
Intention to Adopt Pesticide Reducing Innovations	0.442	0.432

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