D3.5: Report on case studies

WP3 – Benchmarking methodologies and technologies

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Table of Contents

Table of Figures

Table of Tables

Executive summary

This report presents results from tests on smart technologies for monitoring pest and disease in vegetable crops carried out in 2022. The first section outlines the methodology, data collection, trial description and regular and overall evaluations carried out on the technologies tested A second section describe the results from several tests of selected smart technologies from three groups of technologies. Not at least, the third section outlines a summary of outcomes and the fourth and fifth sections end with challenges, perspectives and key findings and recommendations.

Technologies to be tested were suggested after the benchmarking workshop carried out in October 2021. Later on, in a general and on-site assembly held in Bordeaux, France in February 2022, the project partners have tested smart technologies on target vegetable project crops. Eight technologies were tested in Belgium, Germany, United Kingdom, Latvia, Portugal and Spain (Figure 1). Three technology groups 1) monitoring, 2) diagnosis and detection and 3) decision support. The technologies consisted of smart traps and mobile applications and were tested on cabbage, carrot, cauliflower, cucumber, tomato and bell pepper vegetable crops grown in greenhouse or open field.

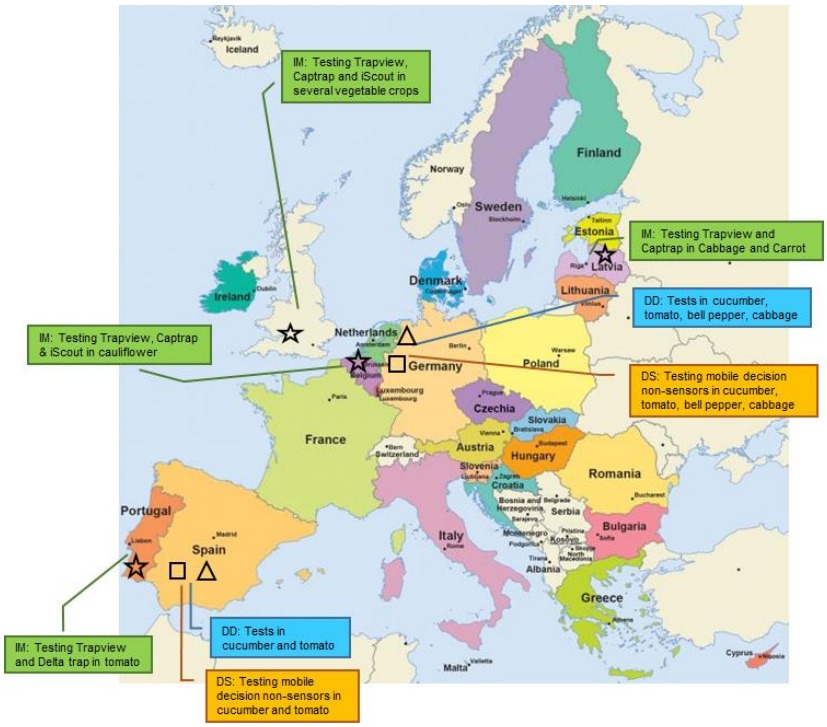

Figure 1 –Technologies on IPM: insect monitoring, DD: decision and detection, DS. Decision Support tested by SmartProtect project country partners in 2022 in target vegetable crops

The smart technologies support during monitoring, but do not provide a quick solution, the user should be first trained on pest and disease identification, then, trained in the management and handling of the technologies. The testing of these technologies has provided interesting and practical results on monitoring pest and diseases over vegetable crops. However, these technologies need to be connected to the Internet or mobile data, otherwise, it is not possible to use them for monitoring pest and diseases in vegetable crops.

1 Introduction

Pest and disease control is a major task in vegetable production, and if it is not carried out adequately, pests and diseases can reduce quality and yield. Therefore, for ensuring good production and yield, a combination of methods is required. Use of pesticides have increased in the world and its reduction is not seen in a very optimist sense (Sharma et al., 2019; FAO 2022a, b). In Europe and according to policies to promote organic agriculture and strict regulation on the use of pesticides is recommended and expected to be reduced to 50% to 2030 (Europe Commision 2022). There is an opportunity for smart technologies to be employed for accurate identification of pests and pathogens, and then for growers to follow up with control methods which might be physical, biological or chemical, if there is a need for a strong intervention.

Crop protection has evolved from the traditional form of manually monitoring insects to camera algorithm technology (Artificial Intelligence, AI). This novel technology reduces labour input and attempts to improve the timeliness of insect control in an effective way and using non-destructive methods. These technologies are based on algorithms, data bank imagery and platforms, and all of them work using wireless systems and the internet. At the moment, some of the devices are available as a service or are leased to growers. Smart monitoring applications for pest and diseases for vegetable crops using mobile phones are accessible for use in open field and greenhouse production systems might help with the identification and monitoring of pest and pathogens.

The use of the new and smart technologies has the advantage of supporting the monitoring of pests and diseases through non-destructive methods. In addition, they can help guide control of pest insects, monitor their abundance, and help the user to make appropriate use of products for pest and pathogen control.

Technologies for pest and disease monitoring crop have been developed from traditional techniques to autonomous, , smart and practical application in crop protection (Walter et al. 2017). Nevertheless, information on manipulation, availability and applicability in vegetable crops are not promoted widely yet (Böckmann and Baklawa 2021; Heitkämper et al. 2023). In view of that, the SmartProtect project has developed an open and free platform that contains information about the smart technologies available, manufactured and imported in Europe. Users from everywhere can search for an appropriate crop protection technology. The platform is available in many languages. The information about the technologies presented in this report is available in the SmartProtect platform, and the user/reader can find further information and get in contact with the manufacturer/provider/importer.

The purpose of this report is to present the results from field tests of smart technologies carried out in the greenhouse and open field in vegetable crops by SmartProtect project partners. The project carried out a benchmarking and a SWOT analysis on technologies in October 2021 (Rodriguez and Böckmann 2022) , and selection of technologies for testing in the field and greenhouse under the common target vegetables was performed in agreement with all project partners in February 2022. Smart traps and mobile applications were tested in vegetable crops by project partners. Trapview produces smart traps and is part of the project consortium. Trapview traps were compared with similar smart traps.

1.1 Objectives

The objective of this report is to present case studies on testing smart technologies comprising of traps and non-destructive technologies for plant and disease identification and monitoring in target crops. The technologies were tested in greenhouse and open field production systems in Belgium, Germany, UK, Latvia, Portugal and Spain.

1.2 Goals

The goals of case studies presentation are:

1. To test the performance of monitoring, diagnosis and detection, and decision support technologies of pest and disease in crop vegetables.
2. To compare results between technologies from performed case studies.

2 Methods

2.1 Approach

Following the benchmarking and SWOT analysis of technologies carried out in November 2021, partners selected certain technologies to test at the general assembly on February 25th. Work package 3 prepared a guide for the surveying and collection of information about the technologies, thus partners could collect information in templates provided and uploaded into the SmartProtect Project SharePoint site.

The technologies were tested and compared in the open field and greenhouse, and consisted of traps and smart mobile applications that are automated, semi-automated or manual. The tools consisted of the insect monitoring, mobile disorder detection, decision support (no sensors) and application techniques depicted in Table 1.

Table 1 – Technologies tested in 2022 in open field and greenhouse by project partners

Technology group	Technology sub-group	Technology	Target crop	Target pest	Production system	Location test
Monitoring	Insect	Trapview	Carrot	Carrot fly	OF	UK, LVA
			Brassica	Diamond-back moth	OF	UK, LVA, BE
			Tomato	Tuta absoluta	GH	PT, ES, UK
		CapTrap	Brassica	*Plutella xylostella*	OF	LVA, BE, UK
		iScout	Cabbage	*Plutella xylostella*	OF	UK, BE
Diagnosis and detection	Disorder detection mobile Apps	Plantix App	Cucumber	Spider mites	GH	DE, ES
			Tomato	Leaf miner fly	GH	DE, ES
			Bell pepper	Ca deficiency	GH	DE
			Cabbage	Flea beetle	OF	DE
		Cropalyser App	Tomato,	Leaf miner fly	GH	DE
			Cucumber	Spider mites	GH	DE
			Bell pepper	Leaf miner fly	GH	DE
			Cabbage	Flea beetles	OF	DE
Decision support	Without sensors	Xarvio Scouting App	Tomato	Spider mite, leaf miner fly	GH	DE, ES
			Brussel sprouts		OF	BE
			Cucumber	Spider mite, powdery mildew	GH	DE, ES
			Bell pepper	Leaf miner fly	GH	DE
			Cabbage	Cabbage white butterfly	OF	DE, BE
		Agrio App	Tomato, Cabbage	Powdery mildew, Flea beetle	GH, OF	DE
		Bioline App	Tomato	Leaf miner fly	OF	DE, BE

OF: open field, GH: greenhouse, BE: Belgium, DE: Germany, ES: Spain, LVA: Latvia, PT: Portugal, UK: United Kingdom

Eight technologies were tested during the 2022 season (Table 1) in the open field and greenhouse vegetables. Automated traps from 3 manufacturers were used for insect monitoring. For the group

diagnosis and detection, two mobile applications were employed to survey disorder detection and three mobile applications without sensors were employed for decision support.

2.2 Data collection

The technologies had their own instructions, management guides and handbooks, and the partners could install and implement them in the field or greenhouse with technical support, or in some case the set-up for the technologies was self-explanatory. IThe no sensor devices decision support devices were installed in smart phones, then, used for monitoring target vegetable crops.

For data collection, a detailed guide was developed and shared with all project partners. This guide had step-by-step information on all the procedures for collecting data and the variables that partners should register in Excel template sheets.

2.2.1 Trial description

Three excel sheet templates were created to collect information about the test of each technology. A first template “trial description” (Table 2) consisted for collect information of the field/greenhouse information. Information on the technology and replications was gathered and a picture of the field design.

Table 2 – Description of table template for collecting information on trial of vegetable crop test of technologies

Trial Name	Bell pepper
Trial Location	Messeweg 11/12, 38104, Braunschweig
Trial Number	one
Trial Area (m²)	20
Trial type *(Open field, Greenhouse)*	Greenhouse - room - C.7
Replicates *(e.g. 1 = PLANTIX APP 1; 2 = PLANTIX APP 2; 3 = PLANTIX APP 3; 4 = CROPALYSER APP 1, 5 = CROPALYSER APP 2; 6 = CROPALYSER APP 3; 7 = AGRI TEX APP 1; 8 = AGRI TEX APP 2; 9 = AGRI TEX APP 3; 10 = manual sampling 1; 11 = manual sampling 2; 12 = manual sampling...)*	Cropalyser App (1 - 8), n = 8, a, b, c Xarvio Scouting App (1 - 8), n = 8, a, b, c Plantix App (1 - 8), n = 8, a, b, c
Additional Information *(Greenhouse <-> open field?, heating?, artificial light?, plastic <-> glass?, soil <-> soilless?, planting distance?, row distance?, ...)*	-Greenhouse -Sweet Pepper var. Bendigo F1/Enza Zaden -Temperature: 20 - 22 Celsius -Substrate: Clay Substrate -three rows, distance between rows = 1 m distance between plants = 0.5 m
Abbreviations *(List of explanations of abbreviations used in the Evaluation files and the trial Overview)*	
Trial overview *(insert trial outline with positions of Application use, samplings, replicates, plant rows, ...)*	>> Insert pptx/jpeg or similar below this table – make a picture

2.2.2 Overall evaluation

The second template gathered information about the “overall evaluation” (Table 3), it helped to gather information on parameters such as working speed, acreage covered, support, mode of operation, accuracy, user friendliness of the technology and the registration crop phenology stages (BBCH scale).

Table 3 – Overall evaluation template with parameters to record information technologies performance

Parameters	Questions	Technology 1	Technology 2	Traditional Technology
Working speed	Time to provide matched pictures on the disease/insect / plant / pot. >> *Averaged estimate for the season. If relevant, split information by species.*			

	Were the insects / disease recognized by the Application and / or Local Standard Method? *Please include the name of insects/diseases.*			
Acreage covered *(it is advised that your Smartphone / Table has enough space for saving the picture)*	How many plants/area? *Plants / Replicate / pictures / no.*			
	How many insects / diseases were identified in the plant? *Insects / disease / plant / pot? Give an overview of the trial.*			
Support from provider / company / platforms	Free support? y / n			
	Time in reacting from provider / hours / minutes / day. *Include the information when the Application needs technical support or when the user requires support from the provider/company, etc.*			
	Paid to the central support? *How much EUR?*			
	Is quick enough the support? y/n			
	Are the support materials free to download? y/n			
Mode of Operation	How long takes on average identifying the insect / disease (plant / min)? Discrepancies during tests?			
	How easy/complicated is the handling?			
	Does is available in your language?			
	Which operative system use Android or iOS (Iphone / Ipad)?			
	Does this Application work with Data / Bluetooth / WiFi / WLAN?			
Accuracy	Do the Application provide a correct picture / correct identification on the insect/disease? *y / n Please include one answer per sampled pest.*			
	Does the result match with traditional method used? *Describe it. Please include one answer per picture / disease / insect*.			
	Is it better / as good as / better than the traditional method?			
User-friendliness	INITIAL LAUNCH: Does the smart Application run at the beginning without difficult? *It is advised that the Smartphone or Tablet be connected to Wi-Fi / Data / Internet.*			
	DURING USAGE: Is the working process of the Application self-explanatory?			
	Are the results clear and easy visualized?			
Phenology Stage	Please, insert the Date and hour when the Smart Application is used			
	Include the BBCH-scale phenology stage when the Smart Application was used to identify insect / disease on plant / pot?			

2.2.3 Regular evaluation

The third template (Table 4) helped to gather information of “regular evaluation”, which consisted of technology employment on a daily or weekly basis. The partners filled in the information when the technology was employed during the identification, monitoring, and collection of information on the pest/disease in the target crop. Information on BBCH scale was recorded to keep in to account the plant stage when was monitored.

Table 4 – Table template to collect information on daily regular evaluation from technology test

Trial name number	Crop name	Crop variety	Date	Technique	Rep	BBCH	Working duration (sec)	Result Disease - LEAF	Working duration (sec)	Result Disease - FRUIT
C.7	Bell pepper		05.07.2022	manual	1					

C.7	Bell pepper		05.07.2022	manual	2					
C.7	Bell pepper		05.07.2022	manual	3					
C.7	Bell pepper		05.07.2022	manual	4					
C.7	Bell pepper		05.07.2022	manual	5					
...	….		….	….	1					
…	….		….	….	2					

3 Results

This section presents case studies on the technologies tested by the project partners during 2022. Eight technologies were tested on vegetable crops and are presented as cases per technology group. Tools in three technology groups were tested: monitoring, diagnosis and detection and decision support.

3.1 Monitoring technologies group

3.1.1 'Insect monitoring' sub-group

3.1.1.1 Testing Trapview and Delta trap for *Tuta absoluta* in a tomato crop in Portugal

Testing of smart traps from Trapview and traditional trap Delta traps were carried out by the Instituto Nacional de Investigação Agrária e Veterinária, I.P. (INIAV) in Portugal (Table 5). The test was performed in a tomato crop in a greenhouse. The system of production was based in soilless substrate.

Table 5 – Trial description for the smart technology test

Trial Name	**Trapview and Delta trap in tomato monitoring**
Trial Location	A. dos Cunhados (Portugal); coordinates (1) 39,1335; 9,34266667, (2) 39,13269444; 9,34316667
Trial Area (m²)	3 ha
Trial type	Greenhouse
Replicates	(1) 1, 2 = Trapview-trap 2 (Devices nos. S06936 and S06937); (2) 3, 4 = Delta trap 2 (nos. 36-D and 37-D)
Additional Information	Greenhouse, no artificial heating, no artificial light, plastic, soilless, planting distance = 20cm, row distance = 2m, natural ventilation with computer-controlled windows on top

There were two replicates of each trap, and they were set up in the tomato crop in the greenhouse. The test was performed in an area of 3 hectares. Monitoring activities were performed between February and June 2022. All data recorded by Trapview was examined remotely and the Delta trap was examined weekly or monthly.

3.1.1.1.1 General overview of performance of traps tested

Tomato is one of the most cultivated and consumed vegetable crops in Europe and the world. According to Eurostat (2021), Portugal is the third largest producer of tomatoes in Europe, with a production of approximately 1.8 M tonnes. Portugal has temperate climate which is appropriate for growing tomatoes.

Table 6 – Overall evaluation of smart trap and traditional trap in insect monitoring in tomato crop in Portugal

Parameters	Questions	Trapview	Delta trap (traditional trap)
Working Speed	Time to provide matched pictures on the insect	Daily, at night	15-30 days interval
	Is it faster than the local standard method?	Faster	Visual counting with the help of a magnifying glass
	Were the insects recognized by the SmartTrap and traditional method?	Yes, *Tuta absoluta*	Yes, *Tuta absoluta*
Acreage covered	How much does it cover in terms of land/area?		
	How many insects were captured during the trial? Insects/cm^2?	80 in two traps (20×34 cm^2)	164 in two traps (each 10×17 cm^2)
Support from provider	Free support? Y / N	No for the trial	Not
	Time in reacting from provider / hours / minutes / day	Daily	The farmer should visit the trap
	How much is paid to the provider for the support?		
	Is it quick enough the support? y/n	Yes	Not
	Are the support materials free to download? y/n	Yes	
Mode of Operation	How long does it take to monitor an area and time (m^2/min)?	Daily	
	How easy/complicated is the handling?	Device assembly and software installation are not easy. Trap setting up in greenhouse requires time. It needs at least 2 persons.	Easy
	Does it work with battery, solar panel, or other?	Yes	Not
	Does the technology work manual or it work manual or automatized with analytic software?	Automatized with analytic software	Manual
	Does this device work with Data / Bluetooth / Wi-Fi?	Yes	Not
Accuracy	Do they provide a correct picture of the insect? y/n	Yes	Not
	Does the result match with traditional method used?	Trapview catches were lower compared to the Delta trap	
	Is it better / as good as / better than the traditional method?	Better than	
User-friendliness	INITIAL LAUNCH: How long needs initially to put tool into operation? Self-explanatory? Support?	2 days	10 minutes
	DURING USAGE: Is the working process self-explanatory?	Not very friendly	
	Are the results clear and easy visualized?	So so	
Phenological Stage	When the smart trap evaluation and information collected by the Smart Trap from the crop	11/13/2022	After collecting the plates
	BBCH-scale phenology stage recorded during the Smart Trap evaluation on insect monitoring and data collection.	Not	no

Working speed: Trapview provided results daily and could remotely report insect captures, while the Delta trap required a visit either every two weeks or once a month.The Delta trap also requires a magnifying lens for counting and recognising the *T. absoluta* (Table 6).

Acreage covered: Delta trap captured a higher number of *T. absoluta* (164) in two traps, while Trapview captured less (80) (Figure 2) but has many advantages like recognition of pest/insects, counting and outcomes are transmitted to the platform.)

Support from provider: Trapview can provide support, although in the test, the support was not required. In contrast, Delta trap needed a daily checking by a farmer or technician.

Mode of operation: Trapview needed the assistance of two people for and the set up and software installation. The Delta trap does not require any technical assistance or knowledge and the set-up is easy.

Accuracy: Trapview captured and with the incorporated camera, the insects were *T. absoluta*, although the number of captured were lower in comparison of Delta trap. However, Delta trap was not accurate.

User friendliness: Trapview requires training, which can take up to two days to properly understand. For theDelta trap, the set up only took 10 minutes for it to function as intended.

Phenological stage: This parameter was not recorded during the test.

3.1.1.1.2 Traditional trap and smart trap

The attack of *Tuta absoluta* on tomato crop occurs during the plantsentire cycle, and the damage of the crop can reach up to 100%. If it is not detected and appropriately controlled it can reduce plant performance, fruit yield andquality. There are several methods for the control of this pest, which range from organic to chemical. Nevertheless, its detection and monitoring in a timely fashion is important.

Total number of captured *T. absoluta* specimens in the Delta trap (164) was higher after five months than Trapview (84) (Figure 2). The range of the total number of captures in a single month varied from 3 to 30 individuals in Trapview, and from 2 to 31 individuals in the Delta trap.

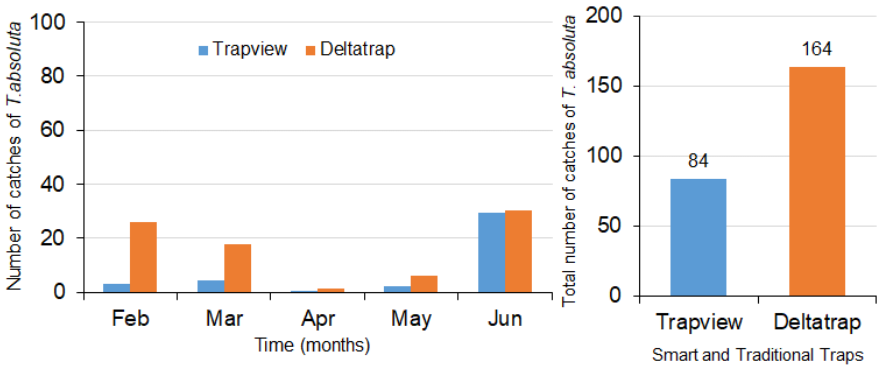

Figure 2 – Mean (n = 2) and total numbers of T. absoluta captured in tomato crop at greenhouse using Trapview and Delta traps

Delta trap on average captured a higher number of *T. absoluta* in February (26) and March (18), in contrast, Trapview captured less, (3 and 5 respectively). However, in June, both traps captured a high number of individuals with 30 and 31 captures for Trapview and Delta trap respectively.

3.1.1.2 Testing Trapview, Captrap and iScout in cauliflower crop in Belgium

Three smart traps were performed in cauliflower vegetable crop by the institute INAGRO in Belgium. A traditional trap was compared among the smart traps (Table 7). The traps were set up in two varieties of cauliflower.

Table 7 – Trial description for the smart traps test over cauliflower crop

Trial Name	**Trapview, Captrap and iScout in Cauliflower crop**
Trial Location	Ieperseweg, 8800 Roeselare, Belgium
Trial Area (m²)	1500
Trial type	Open field
Replicates	2 replicates by each trap: traditional, Trapview, iScout, Captrap
Additional Information	Cauliflower (Brassica *oleracea* var. botrytis subvar. cauliflora - BRSOB) Cultivars: 1° round: David (Syngenta); 2° round: Giewont (Seminis) planting distance: 70×51 cm

Each smart trap had two replicates, as did the traditional trap. Monitoring activities were performed from May to September 2022. All of the data recorded by the smart traps was remotely examined daily, while the traditional method/traps were physcially examined daily.

3.1.1.2.1 Traditional trap and smart traps performance

Plutella xylostella or Diamondback moth is an important pest in Brassicaceae vegetable crops (cauliflower, broccoli, cabbage, and kohlrabi). The damage of this pest occurs when the moth is in its larval stage andwithout proper monitoring and control, the pest can reduce the quality of product and impact the yield.

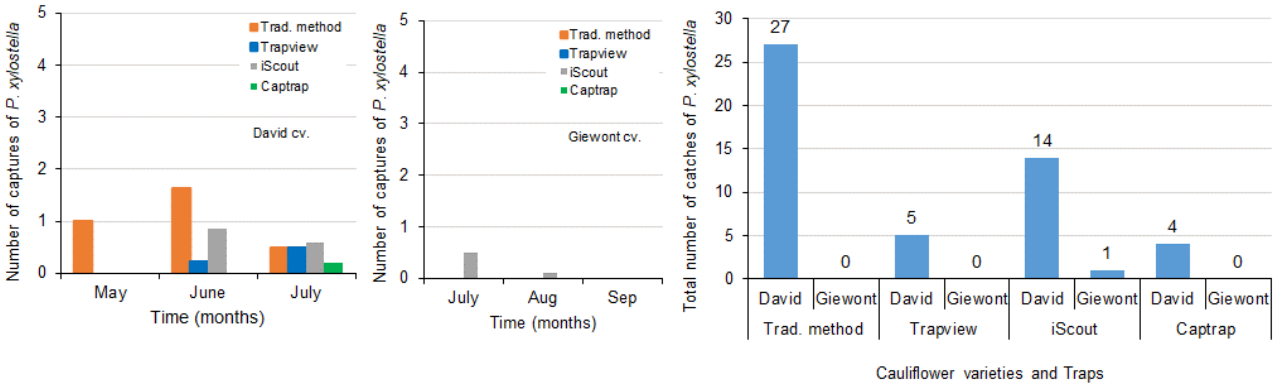

Figure 3 – Mean (n = 2) and total numbers of P. xylostella captured in cauliflower crop in open field using smart traps and traditional traps

David cultivar cauliflower was monitored from May to July and Giewont cultivar was from monitored from July to September. On average, the number of captured moths were lower from May to July (Figure 3). The total number of captured moths of *P. xylostella* was higher for the David cultivar (27) in traditional trap/method, followed by iScout (14), Trapview (5) and Captrap (4). In contrast, no moths were captured in the Giewont cultivar.

3.1.1.2.2 General overview of performance of smart traps and traditional traps

The Smart traps and a traditional trap were evaluated considering their performance for monitoring in field and their efficacy of use.

Working speed: Trapview, iScout and Captrap traps provided results almost instantly. The traditional trap took one minute to identify. In contrast, Captrap and iScout did sometimes not correctly identify the insect (Table 8).

Acreage covered: this parameter was not considered, because only the target insect was counted.

Support from provider: Trapview, assisted when technical support was needed as it is a part of the project consortium. While for Captrap and iScout, materials and guidelines are freely available.

Mode of operation: Versatile and easy to operate, Trapview was easy to manage, the trap is sustained by a solar panel and a battery, this is similar with Captrap and iScout. These traps can transmit data by 4G network; In contrast, the traditional method was carried out manually for the counting and collection of data.

Accuracy: Trapview could identify Diamondback moth (*Plutella xylostella*), due to its well-trained algorithms. In contrast, iScout and Captrap could not identify the moth, the identification was wrong. Insects in Captrap were wrong identified and when insect was present the system did not recognize them (false-positive and false-negative outcome). The traditional trap captured more moths than the smart traps.

User friendliness: traditional trap was quick to set up and operate, while the iScout trap was slow and took at least four hours to start because of troubleshooting a SIM card problem. Trapview took around one hour to start and Captrap needed 15 minutes. In terms of results, Trapview provided clear visual output.

Phenological stage: the smart and traditional traps were used when cauliflower was between 19 and 49 BBCH scale.

Table 8 – Overall evaluation of smart trap and traditional trap in insect monitoring in cauliflower crop in Belgium

Parameters	Questions	Trapview	Captrap	iScout	Traditional trap
Working Speed	Time to provide matched pictures on the insect.	Almost instant - seconds	False positives and negatives (Insects were wrong identified and when insect was present the system did not recognize them)	Almost instant	1 minute per trap (excl. transport to field)
	Is it faster than the local standard/established method?	Yes			-
	Were the insects recognized by the SmartTrap and traditional method?	Yes	Not	Not	Yes
Acreage covered	How much does it cover in terms of land/area?	Not applicable in this trial design			
	How many insects were captured during the trial? Insects/cm^2?	Only the target pest was counted, see regular evaluation			
Support from provider	Free support? Y / N	Yes		Not	Not
	Time in reacting from provider / hours / minutes / day				
	How much is paid to the provider for the support?				
	Is it quick enough the support? y/n	Yes			
	Are the support materials free to download? y/n	Yes	Not	Yes	Yes
Mode of Operation	How long does it take to monitor an area and time (m^2/min)?				
	How easy/complicated is the handling?	Easy	Very Easy	Easy	Very easy
	Does it work with battery, solar panel, or other?	Battery and solar panel			Analogue
	Does the technology work manual or automatized with analytic software?	Automated analytics			Manual
	Does this device work with Data / Bluetooth / Wi-Fi?	4G network, Bluetooth	4G	4G	Not
Accuracy	Do they provide a correct picture of the insect? y/n	Yes			
	Does the result match with Traditional method used?	Yes, best algorithm of the tested traps	Yes, but the algorithm is not trained to recognize Diamondback moth	Yes, second best algorithm	Yes
	Is it better / as good as / better than the traditional method?	In this trial, the local standard captured more moths, but pressure was too low to make a sound conclusion			
User-friendliness	INITIAL LAUNCH: How long needs initially to put tool into operation? Self-explanatory? Support?	1 hour	15 minutes (needed to make support)	4 hours (troubleshooting SIM card)	5 minutes
	DURING USAGE: Is the working process self-explanatory?	Yes	Yes	Yes	Yes
	Are the results clear and easy visualized?	Yes	Not fully		Not
Phenological Stage	When was the smart trap evaluation and information collected by the Smart Trap from the crop	May 24 to Sep 30	June 15 to Sep 30	May 24 to Sep 30	May 24 to Sep 30
	BBCH-scale phenology stage recorded during the Smart Trap evaluation on insect monitoring and data collection.	BBCH 19 to 49	BBCH 19 to 49	BBCH 19 to 49	BBCH 19 to 49

3.1.1.3 Testing Smart traps in cabbage and carrot crops in Latvia

Smart traps were tested in cabbage and carrot crops in two sites by LatHort institute in Latvia. Two crops were monitored: cabbage and carrot in open field conditions (Table 9).

Table 9 – Trial description for the smart traps test in two locations on cabbage and carrot

Trial Name	Trapview and CapTrap – Cabbage	Case study on Trapview – Carrot crop
Trial Location	Two locations: (1) LatHort; (2) farm "Bračas	Farm "Bračas" and two plots: Plot (1) and plot (2)
Trial Area (m²)	(1) 50 m^2 and (2) 5 ha	(1) 3 ha and (2) 9 ha
Trial type	open field in both places	open field
Replicates	in each location one replicate of trap	two replicates (plots)
Additional Information	row distance 60 cm, between plants in row 50 cm	three row beds - 1.5 m between centres of beds
Trial overview	(1) In LatHort: Trapview and Captrap traps were placed in 20 m distance each from other in the trial plot. (2) In Bračas farm: only Trapview trap was used. Moth visual observations (control) were performed weekly by inspecting insect appearance when walking in the field.	Only, Trapview traps were placed one per plot. Visual observations were made in both plots. As carrot fly detection is not yet developed in Trapview, the test purpose was for algorithm development and system "learning".

Trapview traps were employed from June to September and Captrap from June to August (Table 9). For monitoring the cabbage crop, Trapview and Captraps were used at the LatHort location, and in Bracas farm, only Trapview was employed. In the carrot crop, the test was carried out at the Bracas farm, on two plots, and only Trapview was employed. Traps were remotely examined and visually examined on the locations for the manual and traditional monitoring of pest were carried out each week.

3.1.1.3.1 Smart traps performance in cabbage and carrot

Cabbage and carrot are two major vegetables, consumed worldwide. Latvia cultivates both crops and they are either sold for local market or are exported.

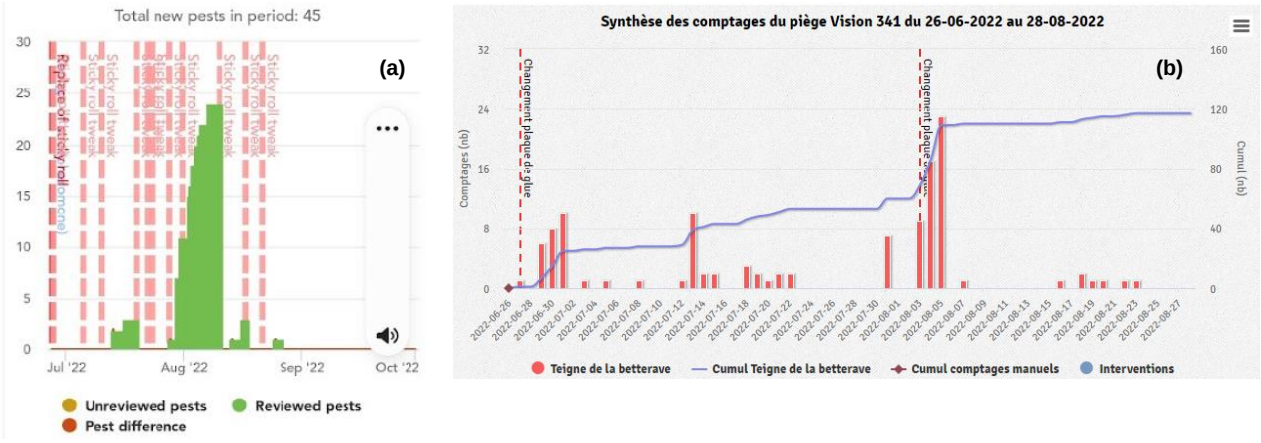

Figure 4 – Number of captures of P. xylostella captured in (a) Trapview and (b) Captrap

Trapview output was provided in English language, while Captrap was available only in French. Trapview monitored *P. xylostella*, however Captrap recorded the insects as beet moth (*Scrobipalpa ocellatella*) (Figure 4).

3.1.1.3.2 General overview of performance of Trapview and Captrap in cabbage crop

An evaluation of Trapview and Captrap performance in cabbage cropaccording to the following parameters:

Working speed: Trapview monitored remotley with an incorporated camera in the trap and reported several times daily according to the settings. Captrap reported pictures of the insect captures daily. For both traps, Diamondback moth (*P. xylostella*) was the target to identify and capture. Although, Captrap does not have Diamondback moth included in their system and the insect identified was actually beet moth (*Scrobipalpa ocellatella*), or in French *"la teigne de la betterave"* (Figure 3).

Acreage covered: Trapview captured 45 insects in the period of monitoring from June to September 2022 in each trap. In contrast, Captrap captured 117 insects per trap. Additionally, to compare the precision of the traps, visual inspections were made.

Support from provider: Trapview recorded the information, which is accessible in the trap digital platform at any time, technical support could also be contacted at any time. Technical support for both traps were free in this case for a test.

Mode of operation: Both traps, Trapview and Captrap many pictures remotely daily. Traditional monitoring by a technician or farmer was done once a week by visual observation.

Accuracy: Trapview has an advantage as the captured insect of interest was marked in the picture. In contrast, Captrap does not have this form of marking in the picture. As in a traditional way of recognizing, it required an experienced farmer or scientist where after a visual observation and collection of samples they could provide the correct name of the insect.

User-friendliness: Trapview took around 1 hour to set up and start using with the instructions provided in English. Captrap took around a half hour, short and sufficient instruction was available in English.

Phenological stage: Both traps were used when cabbage was in BBCH scale of 13 and 45.

3.1.1.3.3 General overview of performance of Trapview in carrot crop

Carrot is an important crop in Latvia. One of its most important pests is *Psila rosae* or carrot root fly. Its larvae damage the root of the crop and can therefore reduce the quality of root. Trapview trap was tested in carrot crop and its performance was evaluated through the following parameters:

Working speed: During this trial, Trapview was in the process of developing an imagerecognision algorithm for *Psila rosae. The pictures gathered from the case study field were used to train the algorithm.* Visual recognition of the fly in the field is not easy, and the damage and negative effects of it are found out after harvesting, when in the root larvae are present. Usually this traditional form of recognition/identification is only made possible when carrots are stored.

Acreage covered: The Trapview traps did not work directly for the recognition of *Psila rosae*, and the so the trial was entirely for the process of machine learning.

Support from provider: Technical support was free as the use of Trapview was part of the project. The data is available in the trap platform and its virtual application in the smart phone.

Mode of operation: A SIM card is needed for the use and starting up of the trap. The trap is automated, works autonomously and is powered by a small solar panel.

Accuracy: The pictures of the captured and target insects were not provided in the season of 2022. In contrast, smanual identification which requires well trained and experienced staff was needed.

User-friendliness: Setting up and understanding how the smart trap worked required at least 1 hour of time, it also requires training for the use of the Trapview platform.

Phenological stage: Trapview was used when carrot plants were in BBCH scale 11 and 49.

Table 10 – Overall evaluation of smart trap and traditional trap in insect monitoring in cabbage crop in Latvia

Parameters	Questions	Trapview	Captrap	Traditional Method
Working Speed	Time to provide matched pictures on the insect?	Several times per day – depends on settings	Any day of the installation period, in one-day data is collected and present	Farmer or scientist performs field observations weekly based on his experience
	Is it faster than the local standard/established method?	yes		n.a.
	Were the insects recognized by the SmartTrap and traditional method?	Diamondback moth (*Plutella xylostella*) was recognized, although in the season was not present with severe spreading		Diamondback moth (*Plutella xylostella)* was recognized by visual inspection, although the year of test, it had not severe presence
Acreage covered	How much does it cover in terms of land/area?	LatHort: 50 m^2, "Bračas": 5 ha	LatHort: 50 m^2	In LatHort: 50 m^2, "Bračas": 5 ha
	How many insects were captured during the trial? Insects/cm^2?	45 new pests captured per trap of a sticky plate of approx. A5 size (14.8×21cm)	Cumulative 117 per trap in a sticky plate of A5 size	By visual field inspection without using any traps, just some insects are recognised
Support from provider	Free support? Y / N	Yes		
	Time in reacting from provider / hours / minutes / day	Data is available in Trapview platform and app at any time. Support team needs to be contacted about technical support.	Data in Captrap platform is daily available. Technical support is assisted by e-mail when is required.	
	How much is paid to the provider for the support?	For trial, it was free.	Trap renting cost is 348,60 EUR, but support is for free	
	Is it quick enough the support? y/n	Yes		
	Are the support materials free to download? y/n	Free, provided by the team by e-mail	Yes	
Mode of Operation	How long does it take to monitor area/time (m^2/min)?	Day, independently from area	Day, independently from area	On the weekly basis half, a day per week takes to inspect field of 5 ha
	How easy/complicated is the handling?	Moderate	Very easy	
	Does it work with battery, solar panel, or other?	Solar panel	Solar panel	
	Does the technology work manual or it work automatized with analytic software?	automatized with analytic software		
	Does this device work with Data / Bluetooth / Wi-Fi?	SIM card should be installed	SIM card installed – no need installation	
Accuracy	Do they provide a correct picture of the insect? y/n	Picture from traps provide marked insects of interest	Picture from traps provide with no marked insects of interest	Insect can be easily identified in the field by experienced farmer or scientist
	Does the result match with traditional method used?	In general, yes, but trap provided more precise information		Visual observations are approximate - not number of Insects can be estimated
	Is it better / as good as / than the traditional method?	Better		
User-friendliness	INITIAL LAUNCH: How long needs initially to put tool into operation? Self-explanatory? Support?	60 min; rather complicate, needs detailed information in the software, and staff support and explanations.	30 min; yes, self- explanatory; easy to install; no need for any support	
	DURING USAGE: Is the working process self-explanatory?	It is supposed to be self-explanatory, but it was partly so.	Yes, but Captrap installation and results are available in French.	
	Are the results clear and easy visualized?	Yes		
Phenological Stage	When the information on evaluation was collected by the Smart Trap from the crop?	Evaluation was performed during the growth period. Daily results from evaluation are available in Trapview platform, and can be downloaded in any time		BBCH 13-45
	BBCH-scale phenology stage recorded during the Smart Trap test on insect monitoring and data collection.	Manually can be entered in platform (?).	Not	BBCH 13-45

Table 11 – Overall evaluation of smart trap and traditional trap in insect monitoring in carrot crop in Latvia

Parameters	Questions	Trapview	Traditional method
Working Speed	Time to provide matched pictures on the insect?	Several times per day - depends on settings	Field observations do not give clear information on carrot fly presence. The damages can be recognized only `*post factum*` when roots are in the storage house.
	Is it faster than the local standard/established method?	Yes	n.a.
	Were the insects recognized by the SmartTrap and / or traditional method?	Carrot fly (*Psila rosae*) was recognized, although the algorithm is not developed yet	No severe damages of carrot fly (*Psila rosae*) were detected in the season
Acreage covered	How much does it cover in terms of land/area?	In farm "Bračas" - 9 ha and 3 ha	In farm "Bračas": 5 ha
	How many insects were captured during the trial? Insects/cm^2?	Program does not work on the carrot fly yet; we participated in the process of machine learning	Insects were not captured during the growth period in normal farming practice at all - as it was not possible
Support from provider	Free support? Y / N	Yes	
	Time in reacting from provider	Data is available in the platform and app at any time. Support team needs to be contacted about technical support.	
	How much is paid to the provider for the support?	For trial, it was free	
	Is it quick enough the support? y/n	Yes	
	Are the support materials free to download? y/n	Should be requested and are provided by the team by e-mail	
Mode of Operation	How long does it take to monitor an area and time (m^2/min)?	A day independently from area	Is not possible to monitor without any traps, if used traps, visual evaluations are according to experience. Depends on experience and knowledge of farmer on the carrot fly.
	How easy/complicated is the handling?	Moderate	Visual inspection is impossible. Traps can be installed but, is needed experienced staff to identify carrot fly from other flies
	Does it work with battery, solar panel, or other?	Solar panel	
	Does the technology work manual or it work automatized with analytic software?	Automatized with analytic software, which is under development at the moment	
	Does this device work with Data / Bluetooth / Wi-Fi?	SIM card should be installed	
Accuracy	Do they provide a correct picture of the insect? y/n	Picture of all traps are provided with marked insects of interest after completion of program development	Visual observations of the traps are depending on the experience of staff
	Does the result match with traditional method used?	In general, yes, but the trap gives more precise information	Visual observations of the traps depend on the experience of the staff, in most cases precise detection is impossible
	Is it better / as good as / than the traditional method?	Better	
User-friendliness	INITIAL LAUNCH: How long needs initially to put tool into operation? Self-explanatory? Support?	60 min; rather complicate, needs to enter quite detailed information in the program, and needs staff support and explanations.	
	DURING USAGE: Is the working process self-explanatory?	Seems that it was supposed to be such, but it was partly so.	
	Are the results clear and easy visualized?	Yes	
Phenological Stage	When was the smart trap evaluation and information collected by the Smart Trap from the crop	Evaluation performed during in growth period. Evaluation results are available on-line and daily working period, can be collected and downloaded in any time	BBCH 11 – 49
	BBCH-scale phenology stage recorded during the Smart Trap evaluation on insect monitoring and data collection.	BBCH 11 – 49	BBCH 11 – 49

3.1.1.4 Testing smart traps in vegetable crops in the United Kingdom

Insect monitoring is important for timely accurate control of insect pests to help avoid potential crop damage that can result in serious yield losses. The University of Warwick tested smart traps in several vegetable crops during the growing seasons of 2021 and 2022.

3.1.1.4.1 General overview of tested smart traps in vegetable crops

In the UK, Smart traps from 3 companies were tested as well as standard techniques for insect monitoring in several vegetable crops, according to the following parameters:

Working speed: Pheromone traps were used to monitor *Plutella xylostella*, *Autographa gamma* and *Tuta absoluta* males. The Trapview traps recognise all three species. Numbers of *P. xylostella* were low in 2022 and although the Trapview, Captrap and iScout traps were used for *P. xylostella* they did not capture any moths. A Captrap trap was also used for *Agrotis* segetum but also did not capture any moths. Coloured sticky plates were used with the Trapview and iScout traps to monitor bean seed fly (*Delia platura*) and with the Trapview traps to monitor carrot fly (*Psila rosae).* Both species were captured by the Trapview traps, but these did not appear to be in such large numbers as those captured by conventional sticky traps. However, there were too few Smart traps to undertake a replicated experiment. Neither *D. platura* nor *P. rosae* are recognised by the Smart traps and remote identification of *D. platura* is particularly difficult.

Acreage covered: All the traps were set up in demonstration areas with small plots of a range of crops, rather than in large fields.

Support from provider: In the United Kingdom there is technical support for Trapview traps. For Captrap the online support is satisfactory, and iScout trap had good technical support.

Mode of operation: The setting up and operation of Trapview and iScout traps was quite complicated. In contrast, the Captrap did not provide any difficulties. All smart traps need an internet connection or Wi-Fi.

Accuracy: Trapview was precise in recognizing *Plutella xylostella, Autographa gamma* and *Tuta absoluta*, but could not recognize *Delia platura* or *Psila rosae*. User-friendliness: The Trapview and iScout traps needed between one to two hours to get started, which included the setting up of the smart trap. Both smart traps were not self-explanatory.

Phenological stage: Trapview was used three times: a) in 2021 and 2022 from April - October (*Delia platura*), b) in summer 2022 for *Plutella xylostella* and *Psila rosae*. And 3) in autumn 2022 for *Tuta absoluta*. Captrap was evaluated in summer 2022 for *Plutella xylostella* and *Agrotis segetum*, as was iScout trap for *P. xylostella* and *D. platura*. BBCH scale for phenology of plants was not recorded as the traps were installed in many crops.

Table 12 – Overall evaluation of smart trap and traditional trap in insect monitoring in several vegetable crops in United Kingdom

Parameters	Questions	Trapview	Captrap	iScout	Traditional Method
Working Speed	Time to provide matched pictures on the insect and differences for species	Overall experience was good. Pheromone traps were used for *Plutella xylostella,* it was seen (very low infestation in 2022), for *Autographa gamma*, for *Tuta absoluta* in a greenhouse and coloured sticky traps for *Delia platura* and *Psila rosae were used.*	Pheromone traps was used for *Plutella xylostella* and *Agrotis segetum* (no captures)	Pheromone trap was used for *Plutella xylostella* (low infestation) and a coloured sticky trap for *Delia platura.*	Pheromone traps, sticky traps, and water traps. All worked as usual. Infestation by *Plutella xylostella* was very low.
	Is it faster than the local standard/established method?	For some species it is good to have daily counts, and this is where the smart trap helps			
	Did the SmartTrap and / or traditional method recognize the insects?	*Plutella xylostella*, *Autographa gamma* and *Tuta absoluta* were recognised by the Smart trap	Captrap did not recognises the insects - we do not catch any in the traps, as there was none around.	This trap in principle can recognise different groups of insects and you can mark them in different colours.	No automatic recognition
Acreage covered	How much does it cover in terms of land/area?	It did not work this out. Mainly one trap per crop/field was set up.			
	How many insects were captured during the trial? Insects/cm^2?	Many for *Delia platura* and *Tuta absoluta.*	None	Not, *Plutella xylostella* and many *Delia platura*.	Many *Delia platura* and *Psila rosae* captured few *Plutella xylostella*.
Support from provider	Free support? Y / N	Yes			
	Time in reacting from provider	Local company based in UK and Trapview provided support. Both responded quite promptly. Some trap had breakdowns and replacement was slow in some cases. Cables on the *Tuta* traps in the greenhouse were installed and the local support did that.	Good online support.	There was quite good support setting the traps up, but one would not work, and it was a long time before we received a replacement.	No support needed.
	How much is paid to the provider for the support?	It is not known			
	Is it quick enough the support? y/n	Usually,	Yes	Not	
	Are the support materials free to download? y/n	Yes			
Mode of Operation	How long does it take to monitor an area and time (m^2/min)?	5 min per trap			
	How easy/complicated is the handling?	Quite complicated	Easy	Quite complicated	Easy
	Does it work with battery, solar panel, or other?	Solar panel			No
	Does the technology work manual or it work automatized with analytic software?	Both			Yes
	Does this device work with Data / Bluetooth / Wi-Fi?	Wi-Fi			Not
Accuracy	Do they provide a correct picture of the insect? y/n	Yes – quality of images can vary	Yes		

	Does the result match with Traditional method used?	Yes, for Lepidoptera and *Psila rosae*. *Delia platura* harder to identify.	Yes, for Lepidoptera.	Yes, for Lepidoptera and *Psila rosae*. *Delia platura* harder to identify.
	Is it better / as good as / than the traditional method?	There is further detailed study than on *Plutella xylostella* and *Autographa gamma*. The traps are as good as the traditional method. Nowadays are improved over time. For *Tuta absoluta* the method is better than the traditional as the traps is visible at any time. However, the batteries do not charge inside greenhouse. For *Delia platura* it is good to be able to see the traps at any time, but identification is difficult remotely. For *Psila rosae*, identification is easier. For the traps that work by visual attraction then it is less easy to orient them at the optimum angle than traditional traps and the camera may obscure part of the trap.	It is as good as the traditional method for Lepidoptera	It is as good as the traditional method for Lepidoptera. For *Delia platura* it is good to be able to see the traps at any time, but identification is difficult remotely. For *Psila rosae*, identification is easier. For the traps that work by visual attraction then it is less easy to orient them at the optimum angle than traditional traps and the camera may obscure part of the trap.
User-friendliness	INITIAL LAUNCH: How long needs initially to put tool into operation? Self-explanatory? Support?	1-2 hours with support	1 hour with support	1-2 hours with support
	DURING USAGE: Is the working process self-explanatory?	Not always	Yes	Not always
	Are the results clear and easy visualized?		Mainly	
Phenological Stage	When was the smart trap evaluation and information collected by the Smart Trap from the crop	1. Evaluated in 2021 and 2022 from April - October (*Delia platura*). 2. Evaluated in summer 2022 for *Plutella xylostella* and *Psila rosae*. 3. Evaluated in autumn 2022 for *Tuta absoluta*.	Evaluated in summer 2022 for *Plutella xylostella* and *Agrotis segetum*.	Evaluated in summer 2022 for *Plutella xylostella* and *Delia platura*
	BBCH-scale phenology stage recorded during the Smart Trap evaluation on insect monitoring and data collection.	Not relevant as they were tested near monitoring plots and in many different crops (*Delia platura, Psila rosae*)	Not relevant as they were tested near monitoring plots with plants of several ages	Not relevant as they were tested near monitoring plots with plants of several ages/

3.2 Diagnosis and detection group

3.2.1 'Disorder detection' sub-group

3.2.1.1 Mobile disorder detection tests in cucumber and tomato crops in Spain

To ensure a good yield in vegetable crops, it is necessary to ensure that the growth and development of the crop has no constraints. Nevertheless, vegetable plants cannot be free of pest and diseases during growth. Monitoring pest attacks and disorder in plants needs to be done by an experienced farmer or technician. Currently, there are some smart applications that can support in the identification of pests and pathogens which might be useful for common vegetables. Two mobile applications were tested for pest and disease monitoring in cucumber and tomato crops (Table 13).

Table 13 – Trial description for the mobile smart applications test in cucumber and tomato

Trial Name	Cucumber	Tomato
Trial Location	Cajamar research centre	
Trial Area (m²)	589 m^2	800 m^2
Trial type	Greenhouse	
Replicates	Plantix App (1-5), n=5; a, b, c, d Xarvio Scouting App (1-5), n=5; a, b, c, d	Plantix App (1-5), n=5; a, b, c, d Xarvio Scouting App (1-5), n=5; a, b, c, d
Additional Information	* Multispans Greenhouse * Monitoring: September – December 2022 * Soil texture: sandy soil * Planting density: 1,25 plants/m^2	* Parral Greenhouse * Monitoring: September 2022 – April 2023 * Soil texture: sandy soil * Planting density: 2 plant/m^2
Trial overview	Sampling: 5 plants per replication were monitored (n = 5), a, b, c, and d. Plants were evaluated once per week from September 2022. Mobile Apps were installed and used in one Smartphone. Disease and pest in the plants were monitored 11 times until 5/12/2022.	Sampling: 5 plants per replication were monitored (n = 5), a, b, c and d. Plants were evaluated once per week from September 2022. Mobile Apps were installed and used in one Smartphone. Disease and pest in the plants were monitored 12 times until 7/12/2022.

3.2.1.1.1 General overview of mobile disorder detection for insect/disease monitoring in cucumber crop

Insect and pest monitoring with the mobile applications Plantix and Xarvio Scouting was tested in cucumber crop under greenhouse conditions. Cucumber is a major crop grown in greenhouses in Spain, particularly in the southern region. Therefore, the use of smart and practical tools for pest and disease monitoring could provide huge potential value for the control of issues and therefore avoidance in yield losses. The applications were evaluated according to the following parameters (Table 15):

Working speed: Plantix and Xarvio Scouting applications needed between 6 to 12 seconds in the identification of pest or disease in cucumber plants. The applications work with internet connection or mobile data. When inspections are made with technicians, this would depend on its time availability. Besides, farmers can be well trained and could support identification of pest and diseases. Known pest and pathogens were identified; nevertheless, unknown and very small insects are not in the list of possible pest and pathogens.

Acreage covered: Five crops were used to test the applications. Not all of crops had any disease or pests to be monitored.

Support from provider: Both mobile applications have support. but The Plantix app has free support and a blog where the user can upload and share a picture of a disease if is not in the list so that the members or users of the Plantix app can help with the identification. In contrast, Xarvio Scouting does not have technical support.

Mode of operation: Identification of pest and diseases with a good internet connection takes between 6 to 12 seconds. Plantix was easy to use, the application could recognize the disease/pest with one picture only, and afterwards, could provide three pictures with the probable disease/pest and include detailed information regarding it. Xarvio scouting also only requires one image, but in contrast, it provides only one image for confirmation by the user for if the identification is correct or not, it then provides a link to it's website for selecting products suitable for the control of the problem.

Accuracy: Plantix identifiedpests very well (e.g., aphis, whitefly or thrips) as well as the disease powdery mildew. The application also provided recommendations in measures to control the identified pest or disease. Xarvio Scouting provides only one picture for the identified disease or pest and then provides a link to the company website for selecting products to use/purchase (Table 15).

User-friendliness: Both applications require that smartphones or tablets are connected to the internet or mobile data, otherwise the application will not work.

Phenological stage: Both smart applications were used eleven times from September to December 2022.

3.2.1.1.2 General overview of mobile disorder detection for insect/disease monitoring in tomato crop

Tomato is an important vegetable crop in Spain, both for domestic use and the export market. Plantix and Xarvio Scouting mobile smart applications were tested in tomato crop in spain and were evaluated through the following parameters (Table 15):

Working speed: Both smart applications, Plantix and Xarvio Scouting required between six to 12 seconds to identify. However, the identification of disease/pest was dependent on the strength of internet connection at the time. In the traditional method of identification, a technician can do this task by visiting the field or greenhouse, if needed; he/she will bring guidebooks to help with the identification. The speed will depend on the technician.

Acreage covered: Five plants were monitored weeklyfrom September to December 2022. Sometimes the plants did not present any symptoms of pest or disease attack.

Support from provider: Plantix is a free smart application, support is free, and the user can receive support from other users' through the platform. The user can share a picture of the disease/pest and ask for help in its identification. The users will help and sometimes provide results about otherwise unknown disease/pests to the platform. In contrast, Xarvio Scouting is a free application with limited features for the user, it has a premium subscription model with a fee for technical assistance.

Mode of operation: Both smart applications, Plantix and Xarvio Scouting, needed an internet connection or loaded with mobile data. When internet flows without any interference, the identification could be between 6 to 12 seconds. However, when the internet was weak, the identification was slow. Plantix requires only one image for identification, it then results with three pictures to compare with the taken picture to help with correct identification. The application then provides the results and recommendations for the control of the issue from organic to chemical treatment. In contrast, Xarvio Scouting, only provides one potential pest/disease image which following user identification then shows the common and scientific name with no description or reccomendations.

Accuracy: Plantix, in this case for the monitoring of pest and disease of tomato could identify *Tuta absoluta,* and powdery mildew. However, more obscure disease or insects are not included in the database of Plantix. Xarvio Scouting application offers only one picture of the potential disease with the highest match rate. Compared with the traditional method of human indentification, both applications are helpful in supporting the identifation of diseases/pest without the need of a book and a trained technician.

User-friendliness: Both mobile applications, Plantix and Xarvio Scouting work with an internet connection and are easy to interpret and understand. Strong mobile data connection is recommended if WIFI connection is not strong.

Phenological stage: BBCH scale was not recorded during this test. The mobile applications were employed from September to December 2022.

Table 14 – Mobile Disorder Detection for insect monitoring in cucumber crop grown in greenhouse in Spain

Parameters	Questions	Plantix App	Xarvio Scouting App	Traditional Method
Working speed	Time to provide matched pictures on the disease/insect /plant.	From the beginning with the picture up to identification of disease/pest, Plantix App needs from 6 to 12 seconds (0.1-0.2 min). But, when internet connection is not good, the identification could take time, or the App will ask for updating. Results outcome will be slow or fail it.	With a good internet connection, the identification was 6 to 10 seconds (0.1-0.2 min). However, if internet is weak, the app will run slowly, and the results will take time.	Technician can do this task, and it will depend on a specialized one. Guidebooks for known and common pest/diseases there are many. However, do not exist description for unknown pest/disease.
	Were the insects / disease recognized by the Application and / or traditional method?	INSECTS recognized: 1. White fly; 2. Thrips and, 3. Aphis DISEASE recognized: 1. Powdery mildew (*Leveillula taurica*)	DISEASE recognized: 1. Powdery mildew (*Leveillula taurica*)	
Acreage covered	How many plants/area?	5 plants per replication were monitored. Sometimes, not all plants showed diseases		
	How many insects / diseases were identified in the plant?	Sometimes, not all plants showed diseases/ pests. In that case, a plant had one to two different insects or diseases, similar results for diseases		Technician identifies diseases and/or pests and sometimes needs a lens to confirm. Pest/Disease Guides, when common diseases or pests are known these materials are useful. For unknown and common pests/diseases, the help of a plant pathologist or entomologist would be needed.
Support from provider	Free support? Y / N	Yes		The work of a disease/pest technician/specialist is paid.
	Time in reacting from provider	The response would depend on internet connection. If the solution is unknown or wrong, the image can be shared, and the community can help when no identification name is not known.	A free version of the app does not have support from the company	It depends on the technician's availability.
	Paid to the central support?	Support is free	No support with free option	It depends on each company
	Is quick enough the support? y/n	Yes		Yes
	Are the support materials free to download? y/n	Yes		Technician can carry some help books in their car.
Mode of Operation	How long takes on average identifying the insect / disease (plant/s)	Depending on internet connection, between 6 and 12 seconds.	Depending on internet connection, between 6 and 10 seconds.	It depends on the experience of the technician
	How easy/complicated is the handling?	It is easy to use. You can take an image on the spot or retrieve it from the gallery. After sending the image, it recognises the crop and provides feedback.	It is easy to use, but you cannot retrieve the photo from the gallery, you can only take a photo. After seen the photo, you must select the crop and give the answer.	It depends on the experience of the technician. He recognises the pest/disease, and he can use a lens.
	Is it available in your language?	<<<<< Yes, in Spanish and in many languages >>>>>		
	Which operative system use Android or iOS?	<<< Android >>>		
	Does this Application work with Mobile data / Bluetooth / Wi-Fi?	Yes, the Apps work with Internet connection, Wi-Fi, or mobile data.		

Accuracy	Do the Application provide a correct picture on the insect/disease? y/n	Yes. Plantix identified very well pests such as *aphis*, whitefly, or thrips (insects identified up to now) and diseases such as powdery mildew. It offers some recommendations for its control related to phytosanitary products, which must comply with the regulations of each country. It should also recommend the use of auxiliary fauna and the implantation of auxiliary plants for pest control.	Xarvio Scouting App provides only one picture for the identified disease	It depends on the experience of the technician. He recognises the pest/disease and can use a lens.
	Does the result match with Local Standard Method used?	Yes, it matches for the pests and diseases studied so far. For Whitefly, describe the symptoms and give three insecticides to select and apply only one.	In the free option, it offers only one image with a higher match rate.	Yes, the technician has confirmed the presence of insect pests (whitefly, thrips) and disease (powdery mildew).
	Is it better / as good as / better than the traditional method?	It is not better than the traditional method, it is a help to identify pests/diseases without the need of a book or a technician. Although, it is not 100% effective, because new types of insects e.g., *Thrips parvispinus* are not detected.	It is not better than the traditional method. It is an aid to identify pest/diseases without the need of a book or a technician.	
User-friendliness	INITIAL LAUNCH: Does the smart Application run at the beginning without difficult?	Yes, it is essential that the smartphone be connected to Internet or mobile data; otherwise, the app will not work.		
	DURING USAGE: Is the working process of the Application self-explanatory?	Yes, it is to follow the indications that appear on the screen. You can select up to 8 crops with which you can work.	With the latest updates, it is easier to use, but with the free option, it is very limited.	
	Are the results clear and easy visualized?	Yes, the results are clear and easy and with description of the symptoms.	The result is very short, as it only provides an image to compare with the damaged leaf with disease, without description of the symptoms.	
Phenological Stage	When was the monitoring and information collected by the smart App from the crop	Plantix App, was used 11 times (14, 22 September 2022; 3, 10, 17, 25 and 31 October 2022; 7, 14, and 28 November 2022 and 5 December 2022) and the plants were monitored from 9 to 10 AM.	Xarvio Scouting App, was used 11 times (14, 22 September 2022; 3, 10, 17, 25 and 31 October 2022; 7, 14, and 28 November 2022 and 5 December 2022) and the plants were monitored from 10 to 11 AM.	
	BBCH-scale phenology stage recorded with the smart App on insect monitoring and data collection.	Plantix App has been used from the beginning of the crop until the beginning of harvest, but the phenological stage has not been recorded	Xarvio Scouting App has been used from the beginning of the crop until the beginning of harvest, but the phenological stage has not been recorded.	

Table 15 – Mobile Disorder Detection for insect monitoring tomato crop grown in greenhouse in Spain

Parameters	Questions	Plantix App	Xarvio Scouting App	Traditional Method
Working speed	Time to provide matched pictures on the disease/insect / of the plant	From the beginning with the picture up to identification of disease or pest, Plantix App needs from 6 to 12 seconds. However, when internet connection is not good, the identification will take more time and just the App will ask for updating. The App will provide the results slowly or fail to provide the output.	When internet connection is good, the identification will take from 6 to 10 seconds. However, if the internet is weak, the app will run slowly, and the results will take time.	Technician can do this task, and it will depend on a specialized one. Guidebooks for known and common pest/diseases there are many. However, do not exist to unknown pest/disease description.
	Were the insects / disease recognized by the Application and / or traditional method?	INSECTS recognized: 1. White fly 2.Thrips *3.Tuta absoluta* DISEASES recognized: 1. Powdery mildew (*Leveillula taurica*)	DISEASES recognized: 1. Powdery mildew (*Leveillula taurica*)	
Acreage covered	How many plants/area? Plants / Replicate	5 plants per replication were monitored. Sometimes, not all plants showed diseases or pest		
	How many insects / diseases were identified in the plant?	Sometimes, not all plants showed diseases or pests. In that case, a plant had one to two types of insects, similar results to diseases	Sometimes, not all plants showed diseases or pests. In that case, one plant, for the moment, had one type of disease.	Technician: identifies diseases and/or pests and sometimes needs a lens to confirm. Pest/Disease Guides: when common diseases or pests are known these materials are useful. For unknown pests/diseases, the help of a plant pathologist or entomologist would be needed.
Support from provider	Free support? Y / N	Yes	Yes	The work of a disease/pest technician/specialist is paid.
	Time in reacting from provider.	The response time depends on the internet connection. If the solution is unknown or wrong, the image can be shared, and the community can help when the solution is not clear.	In the free option you do not have the option of support from the company	It depends on the technician's availability.
	Paid to the central support?	Support is free	No support with free option	It depends on each company
	Is quick enough the support? y/n	<< Yes >>		Yes
	Are the support materials free to download? y/n	<< Yes >>		Technician can carry some help books in their car.
Mode of Operation	How long takes on average identifying the insect / disease (plant/s)? Discrepancies during tests?	Depending on internet connection, from 6 and 12 seconds.	Depending on internet connection, from 6 and 10 seconds.	It depends on the experience of the technician
	How easy/complicated is the handling?	It is easy to use. You can take an image on the spot or retrieve it from the gallery. After sending the image, it recognises the crop and provides feedback.	It is easy to use, but you cannot retrieve the photo from the gallery, you can only take a photo. After sending the photo, you have to select the crop and give the answer.	It depends on the experience of the technician. He recognises the pest/disease, and he can use a lens.
	Is it available in your language?	<< Yes (Spanish), and available in many languages >>		
	Which operative system use Android or iOS?	<< Android >>		
	Does this Application work with Data / Bluetooth / Wi-Fi?	<< Yes, the applications work with Internet, Wi-Fi, or mobile data connection >>		

Accuracy	Do the Application provide a correct picture / identification on the insect/disease? y/n	Yes. Plantix App identifies very well pests such as *Tuta absoluta*, whitefly or thrips (insects identified up to now) and diseases such as powdery mildew. It offers some recommendations for its control related to phytosanitary products that must comply with the regulations of each country. It should also recommend the use of auxiliary fauna and the implantation of auxiliary plants for pest control.	Xarvio Scouting App provides only one picture for the identified disease	It depends on the experience of the technician. He recognises the pest/disease and can use a lens.
	Does the result match with Local Standard Method used? Describe it.	Yes, it matches for the pests and diseases studied so far. e.g., *Tuta absoluta*, the app described symptoms and give three insecticides to select and apply only one.	In the free option, it offers only one image with a higher match rate.	Yes, the technician has confirmed the presence of insect pests (whitefly, thrips, *Tuta absoluta*) and disease (powdery mildew).
	Is it better / as good as / better than the traditional method?	It is no better than the traditional method, it is a help to identify pests/diseases without the need of a book or a technician. It is not 100% effective, because new types of insects such as Thrips *parvispinus* were not detected.	It is no better than the traditional method; it is an aid to identify diseases without the need of a book or a technician.	
User-friendliness	INITIAL LAUNCH: Does the smart Application run at the beginning without difficult?	Yes, it is essential that the smartphone have an Internet or mobile data connection; otherwise, the app will not work.		
	DURING USAGE: Is the working process of the Application self-explanatory?	Yes, it is to follow the indications that appear on the screen. You can select up to 8 crops with which you can work.	With the latest updates, it is easier to use, but with the free option, it is very limited.	
	Are the results clear and easy visualized?	Yes, the results are clear and easy and with description of the symptoms.	The result is very short, as it only provides an image to compare with the damaged leaf with disease, without description of the symptoms.	
Phenological Stage	When was the smart trap evaluation and information collected by the Smart Trap from the crop	Plantix App, was used 12 times (20, 28 September 2022; 6, 13, 19 and 26 October 2022; 3, 8, 16, 24 and 30 November 2022 and 7 December 2022) and the plants were monitored from 9 to 10 AM. Xarvio Scouting app was used in similar dates, but from 10 to 11 AM:		
	BBCH-scale phenology stage recorded during the Smart Trap evaluation on insect monitoring and data collection.	Plantix and Xarvio Scouting apps wered used from the beginning of the crop until the beginning of harvest, but BBCH scale was not recorded.		

3.2.1.2 Mobile disorder detection tests in cucumber, tomato, bell pepper and cabbage crops in Germany

Production of vegetables in western European countries totals up to around 16.2 million tonnes of produce (FAOSTAT 2021). The majority of production of vegetables in Germany is practised under open field conditions (around 113.2 thousand hectares compared with one thousand hectares for greenhouses). In comparison with other European countries, Germany is in the fifth largest producer of Tomatoes (0.2M tonnes).. Tomatoes are also the most consumed vegetable in Germany; with 28 kg/year, cucumber with 7 kg/year and cabbage with 4.7 kg/year (BMEL 2021). It is therefore important that tomato crops are adequately managed for incidences of pests and disease in Germany, to ensure that yields do not suffer. An important aspect of integrated pest management is the diagnosis and detection of pests and diseases, should they occur, which allows for correct further management. This is typically done by inspection of the crops in the field by a trained professional.

Cucumber, tomato, and bell pepper growing in a greenhouse were monitored with Plantix and Cropalyser Apps (Table 16). Each vegetable crop had three replications with eight plants per replicate. During the evaluation and monitoring, not all plants displayed symptoms of pest or disease.

3.2.1.2.1 General overview of mobile disorder detection for insect/disease cucumber crop monitoring in greenhouse

Insect and pest monitoring with the mobile applications Plantix and Xarvio Scouting was done in greenhouse cucumber crop. Cucumber is a major crop grown under greenhouses in Germany and is consumed throughout the entire year. The use of smart and practical tools for pest and disease monitoring of cucumbers can support in the control and therefore avoidance of losses in yield. This makes them a valuable tool. Two smart applications were used to monitor pest and diseases in greenhouse cucumbers and were evaluated according to the following parameters (Table 17):

Working speed: Plantix and Xarvio Scouting smart applications identified pest and diseases in the cucumber crop in under 20 seconds. The identification of pest and diseases during monitoring was quite similar between the two applications. Both applications recognized “thrips”, which is a very small insect, and a specialist verified that this was likely not correct.

Acreage covered: Both applications were employed in eight plants with three replications.

Support from provider: During plant monitoring, both applications had provided good technical support. Plantix has an automatic self-update every two months, and when a user needs support or help in the identification of pest/disease that the app cannot recognise, the app has a blog that the user can upload to and request help from the community. Xarvio Scouting requires a premium subscription fee for specialized technical support.

Mode of operation: Both smart applications are easy to use when they are connected to the internet or mobile data. Plantix has a wide range of vegetable and orchard crops in its library for pest/disease identification, and crop management.

Accuracy: Plantix was accurate, because after submitting one picture, it results in three pictures of diagnosed leaf or fruit with pest/disease. This aids in comparison of the potential pest or disease and it then recommends further management via organic, physical, and conventional control. Xarvio Scouting provides only one picture, if the user confirms it, the app results in its scientific name and a link to the website of the Xarvio company. The user can select products from organic to chemical products for pest/disease control.

User-friendliness: Both apps are well designed, aesthetically pleasing and both require internet connection.

Phenological stage: the applications were employed in four monitoring dates.

Table 16 – Trial description for the mobile smart applications test in cucumber, tomato, bell pepper and cabbage in Germany

Trial Name	Cucumber	Tomato	Bell pepper	Cabbage
Trial Location	Braunschweig, JKI	Braunschweig, JKI	Braunschweig, JKI	Hötzum, Exp. Field, Braunschweig, JKI
Trial Area (m²)	12	12	20	4000
Trial type	Greenhouse – room C.6.2	Greenhouse - room - C.6.1	Greenhouse - room - C.7	Open Field
Replicates	Three replicates (a, b, c) for each monitoring apps: Plantix App and Cropalyser App	Three replicates (a, b, c) for each monitoring apps: Plantix App and Cropalyser App	Three replicates (a, b, c) for each monitoring apps: Plantix App and Cropalyser App	Four replicates (a, b, c, d) for each monitoring apps: Plantix App and Cropalyser App
Additional Information	Glasshouse Monitoring: July month, Temperature: 22°C RH (%): 56.5 Soil texture: loamy Cucumber planted in three rows, distance between rows = 1 m Plant distances = 0.4 m	Glasshouse Monitoring: July month, Temperature: 22°C RH (%): 56.5 Soil texture: loamy Tomato planted in three rows, distance between rows = 1 m Plant distance = 0.4 m	Glasshouse Monitoring: July month Temperature: 20 – 22°C RH (%): 56.5 Sweet Pepper var. Bendigo F1/Enza Zaden Substrate: Clay Substrate distance between rows = 1 m Plant distance = 0.5 m	Open field Monitoring: July and August Field Temperature: 9 – 28°C RH (%): 20 – 60% Soil Texture: clay loamy row intercropping (cabbage/wheat) and row monocrop (cabbage) plants rows distance = 0,5 m Cabbage plants distance = 0,4 m Two types of plots: A) intercropping (cabbage/wheat), and B) monocropping (cabbage)
Trial overview	8 plants per replication were monitored (n = 8; a, b, c) BBCH scale of phenology were recorded. Plants were evaluated weekly in July 2022. Mobile Apps were installed in two Smartphones. Disease/pest in the plants were monitored in four times.	8 plants per replication were monitored (n = 8; a, b, c) BBCH scale of phenology were recorded. Plants were evaluated weekly in July 2022. Mobile Apps were installed two Smartphones. Disease/pest in the plants were monitored in four times.	8 plants per replication were monitored (n = 8; a, b, c) Plants without covering were monitored with Apps on disease and pests in bell pepper plants. BBCH scale of phenology were recorded.	8 plants per replication in borders of selected experimental units (plots) were evaluated. Three times in July and August months. Two replications for monocrop (cabbage) and two for intercrop (cabbage/wheat) were surveyed with the mobile applications. Plants in the borders were used, to avoid any constraints and not to disturb the experiment.

3.2.1.2.2 General overview of mobile disorder detection for insect/disease tomato crop monitoring in greenhouse

Tomato is a popular and highly consumed vegetable in Germany where the population consumes around 28 kg/year (BMEL 2021). It is a highly imported crop, although its domestic production is experiencing a rise. In this case, Tomato greenhouse production in the summer season of 2022 was surveyed. The crops were monitored with two smart applications, Plantix (an automatic image identification app) and Cropalyser (a manual app) were evaluated according to the following parameters (Table 18):

Working speed: Tomato crop is included in both applications; Plantix outcomes were quick below 10 seconds. The Cropalyser App was useful in aiding the efficiency of the crop monitoring and diagnosis, the name of pest and diseases from the Plantix App were used to search and get further descriptions which was helpful.

Acreage covered: eight plants arranged in three replications were monitored with both applications. Sometimes, not all of the plants displayed signs of pest/diseases.

Support from provider: No technical support was needed during monitoring with both applications.

Mode of operation: Both applications are well designed and are not complicated to use. However, Cropalyser requires training on how to operate properly, e.g., the user must be able to identify from a list of crops and the names of pest and disease in order to monitor the crop in the open field or greenhouse.

Accuracy: Both applications were accurate, but it should be noted that the user should have knowledge on common pest and diseases of tomatoes. In the case of Cropalyser, it requires previous knowledge of pest and disease. The name of pest/disease from previous results with names of diseases and pests of Plantix were utilized to find out similar explanation and recommendations. The advantage of Cropalyser is that the pictures are of high quality which helps in the field when comparing potential pests/diseases, it is also available in German.

User-friendliness: Starting, running, and working both applications resulted in no complications when they were connected to the internet, or the smartphones had mobile data. The identification results were well explained.

Phenological stage: Tomato plants evaluated and recorded in four scales of BBCH.

Table 17 – Mobile Disorder Detection for insect monitoring in cucumber crop grown in greenhouse in Germany

Parameters	Questions	Plantix App	Xarvio Scouting App	Traditional method
Working speed	Time to provide matched pictures on the disease/insect / plant	The App employed 7 – 1 seconds. However, when internet connection is not good, the identification might be slow, the App will ask for updating, or fail to provide the output.	Xarvio Scouting App needed 6 to 17 seconds. However, if the internet connection is slow, the identification will take time.	Technician/specialist can identify disease/pests after visits on the crop. Handbooks supported to find the approximate pest/disease, although need time. However, many unknown pest/diseases have not yet description.
	Were the insects / disease recognized by the Application and / traditional method?	Insects recognized: 1. Correct on spider mites 2. Correct on leaf miner flies (Agromyzidae) 3. False-positve on thrips (Insect was not seen at visual inspection) Diseases recognized: 1. Correct on downy mildew (*Pseudoperonospora cubensis*) 2. False-positive on powdery mildew (Erysiphaceae) (not sure)	Insects recognized: 1. Correct on spider mites 2. Correct on leaf miner flies (Agromyzidae) 3. False-positive on thrips (Insect was not seen at visual inspection)) Diseases recognized: 1. Correct on downy mildew (*Pseudoperonospora cubensis*) 2. Correct on powdery mildew (Erysiphaceae) 3. False-positive on powdery mildew (*Pedosphaera xanthii*)	A colleague, specialist could recognize and verified e.g., spider mites, leaf miner fly. Specific book on cucumber cultivation was consulted to verify the identified disease. It needed a previous knowledge to find the correct pest/disease and get the diagnosis.
Acreage covered	How many plants/areas? Plants / Replicate	8 plants per replication were monitored. Occasionally, not all plants showed diseases or pest.		
	How many insects / diseases were identified in the plant?	Sometimes, not all 8 plants showed diseases or pest. If so, one plant had one or two different pest, similar findings with diseases.	Among one or two disease/insect were identified in one plant. However, the user has to choose among identified and what is seen in field.	Technician cannot identify tiny insects e.g.; thrips are not easy to identify; it might need a stereo microscope to confirm on it.
Support from provider	Free support? Y / N	Yes	Not	The work from a technician/specialist for disease/pest is paid and is not free.
	Time in reacting from provider	The App has a blog, and users can upload the picture and ask for help in it. The blog help by pictures from feedback from other users to identify disease/pest.	When the user has a premium subscription, a technician can provide the adviser.	It would depend on the time availability of the technician.
	Paid to the central support?	Support is free	Support is free but limited as free version.	n.a.
	Is quick enough the support? y/n	The App updates every two months, and after that, the app runs without inconvenient	the App has updated every two months, and when is updated the system runs without inconvenient	Requesting the assistance from a company or advice service, it needs a booking in advance, and it is paid.
	Are the support materials free to download? y/n	Yes	n.r.	Technician/specialist will inform if materials are free available or under fees.
Mode of Operation	How long takes on average identifying the insect / disease (plant / s)? Discrepancies during tests?	Between 6 to 12 s	Between 5 to 18 s	Technicians might identify the disease/pest. However, samples will be taken to the laboratory when are small insect and samples of leaf with fungus to identify correctly. Handbook can help if disease/insect have good quality pictures for comparison.

	How easy/complicated is the handling?	Handling is not complicated, it is easy, and the App provides from two to three pictures with good quality to make sure on the identified disease/pest.	The use is not complicated - however, when you got a result, you get only a brief output with a link to the company, which can offer products to apply.	-Technician/specialist can assist during the identification, diagnosis of insects/diseases in vegetables in open filed or greenhouse. Handbooks are easy to use for identification common pest and diseases.
	Is it available in your language?	No is available for German version, but indeed in other languages.	Yes, is available for German version and other languages.	Yes, technician/specialists can talk local languages. Likewise, there are good books on vegetable crop management.
	Which operative system use Android or iOS?	Android		
	Does this Application work with Data / Bluetooth / Wi-Fi?	Yes, the applications work with internet connected		
Accuracy	Do the Application provide a correct picture / correct identification on the insect/disease? y/n	Yes, for disease: Powdery Mildew, the App shows three pictures with good quality and recommend for control from traditional to organic procedures. For pest, the App makes good identification e.g., leaf Miner fly, and had good description and similar steps to control it.	Xarvio Scouting App provides only one picture for the identified disease or insect. When user has selected the identified disease/pest, the app provides a link for selecting products to buy for the control.	
	Does the result match with traditional method used?	Yes, e.g., powdery mildew was similar as described in the book. However, there was a discrepancy with Oidium, not sure if was a correct identification.	The description from the output about the disease/pest is very short - just give the link for purchasing the products from the company.	Yes, for of insects, leaf-miner-fly was confirmed, after specialist consultation. Pictures of powdery mildew were compared with a book on disease/pest of cucumber.
	Is it better / as good as / better than the traditional method?	Is good and helps to identify the disease/pest.	Is not good, when the App recommends connecting to the company and purchase the products.	Technician/Specialist would identify known disease/pest. However, unknown pest will require the work in a laboratory.
User-friendliness	INITIAL LAUNCH: Does the smart Application run at the beginning without difficult?	Yes, once with internet connection, the App is easy to use and select the preferred crop.	Yes, the Smartphone should have internet connection or mobile data. Without these facilities, the application will not work.	
	DURING USAGE: Is the working process of the Application self-explanatory?	Yes, Plantix App is self-explanatory, and the cucumber option is in its menu, which can give further information.	The working process is easy but gives short recommendations for the user can go to website company and look for products.	
	Are the results clear and easy visualized?	Yes, the results are clear and easy, but not available in German version.	The result is short, and only provides a picture to compare with the damaged leaf with disease or insect attack.	
Phenological Stage	When was the disease/pest identification collected by the Smart application from the vegetable?	Plantix App, monitored four times (5, 11, 16, 26 July 2022) and plants were monitored from 10 to 11 AM.	Xarvio Scouting App, monitored four times (5, 11, 16, 26 July 2022) and plants were monitored from 11 to 12 AM.	Pictures from field visit were compared with books.
	BBCH-scale phenology stage recorded during the Smart application use on insect monitoring and data collection.	four evaluations were carried out and the BBCH corresponded (82), (802), (601, 631, 70, 701, 702, 703) two times with similar scale	four evaluations were carried out and the BBCH corresponded (82), (802), (601, 631, 70, 701, 702, 703) two times with similar scale	four evaluations were carried out and the BBCH corresponded (82), (802), (601, 631, 70, 701, 702, 703) two times with similar scale

Table 18 – Mobile Disorder Detection for insect monitoring in tomato crop grown in greenhouse in Germany

Parameters	Questions	Plantix App	Cropalyser App	Traditional method
Working speed	Time to provide matched pictures on the disease/insect / plant	From the beginning with the picture up to identification of disease/pest, Plantix App used 6 – 7 seconds. However, when internet connection is weak, the identification will take more time and the App will ask for updating. The App will provide the results slowly or fail it to provide the output.	This App was used two times. The identification and diagnosis of disease/pest took 11 seconds (0,2 min). The searching of image is manual and should be done in the list of insects, disease, fungus, and virus. After, the disease/pest is selected; the App provides 2 -3 good quality pictures. The pictures were compared with the leaf or fruit.	Technician Handbooks
	Were the insects / disease recognized by the Application and / traditional method?	Insects recognized: 1. Correct on leaf miner flies (Agromyzidae) Diseases recognized: 1. False-positive on tomato late blight 2. Correct on powdery mildew (Erysiphaceae) Physiological disorder: 1. Correct on Mg deficiency 2. Correct on leaf curly	This App monitored and diagnosed the following Insect recognized: 1. False-positive on spider mite (Tetranychidae) Disease recognized: 1. False-positive on powdery mildew (*Oidium neolecopercisi*) Physiological disorder recognized: 1. Correct on fruit cracking 2. Correct on Mg deficiency	Tomato: leaf miner flies (Agromyzidae). Powdery mildew (Erysiphaceae) and the colour spots in leaves due to Mg deficiency. Curly leaves was seen, and it would be needing a verification whether is virus or another physiological disorder or water stress.
Acreage covered	How many plants/areas? Plants / Replicate	8 plants per replication were monitored, sometimes, not all plants showed diseases or pest		Technician Handbooks
	How many insects / diseases were identified in the plant?	Sometimes, not all 8 plants showed diseases or pest. If so, one plant had from one to two insects, similar findings with diseases.	One to two disease/pest were recognized using the comparison of pictures in the data bank of the App.	Technician Handbooks
Support from provider	Free support? Y / N	Yes	Yes	Technician Handbooks
	Time in reacting from provider	Plantix App has a blog, and users can upload the picture, ask for recommendation, and help on not common disease/pest identification.	The App is easy to use but needs internet connection. For specialized support, there is contact information with technical team.	Technician Handbooks
	Paid to the central support?	support is free		Technician Handbooks
	Is quick enough the support? y/n	This App updates itself every two months and should be connected to internet.		Technician Handbooks
	Are the support materials free to download? y/n	Yes	yes	Technician Handbooks
Mode of Operation	How long takes on average identifying the insect / disease? (plant / s)? Discrepancies during tests?	it took between 6 to 7 s	It is made by a manual procedure, if the user has an idea about disease/pest will take around 0.2 min. However, when the user does not know the disease/pest, it will take further time to match the approximately disease/pest.	Technician Handbooks
	How easy/complicated is the handling?	The use is not complicated, and the results cannot be only one option, sometimes can be up to three.	Is not complicate, but the user should have a previous knowledge and idea about the disease/pest to monitor. The Apps provides good quality pictures to compare and facilitate the correct identification.	Technician Handbooks

	Is it available in your language?	Available in many languages but is not for German.	Yes, is available in German version.	Technician Handbooks
	Which operative system use Android or iOS?	<< Android >>		Technician Handbooks
	Does this Application work with Data / Bluetooth / Wi-Fi?	Yes, both applications work with internet connected.		Technician Handbooks
Accuracy	Do the Application provide a correct picture / correct identification on the insect/disease? y/n	Yes, e.g., Powdery Mildew, Plantix App provides three pictures with good quality and recommendations for controlling disease. In the case of insect, e.g., Leaf Miner fly, it had a clear description and similar recommendations.	It will depend on user's knowledge and matching the approximate picture of disease/pest target. The results from other Apps were used to search and to match with the right disease/pest target.	Technician Handbooks
	Does the result match with traditional method used?	Plantix App does recommend least three possibilities for disease and pest control.	When a matched picture fits in, and after comparing with the leaf or fruit with disease/pest - the result with the description helps for plant protection.	Technician Handbooks
	Is it better / as good as / better than the traditional method?	Identification of diseases and pests with Plantix App help in the diagnosis in greenhouse.	It is a good method when the user knows, however it needs a previous knowledge on disease/pest names.	Technician Handbooks
User-friendliness	INITIAL LAUNCH: Does the smart Application run at the beginning without difficult?	<< The Apps works with internet connection >>		Technician Handbooks
	DURING USAGE: Is the working process of the Application self-explanatory?	Yes, the use of Plantix App, is self-explanatory, and the tomato plant is in the list of plants for identification. Besides provides a weather information on the site of monitoring and recommendation on practices.	The App has a list of known crops, and either the app provides a list of disease, fungus, insects, virus to compare and recognize in the field or greenhouse.	Technician Handbooks
	Are the results clear and easy visualized?	Yes, the results are clear and easy, but not available in German version.	Yes, two or three pictures with good quality of the disease/pest is provided to support during the in-situ comparison.	Technician Handbooks
Phenology Stage	When was the disease/pest identification collected by the Smart application from the vegetable?	Plantix App, was used four times (5, 11, 16, 26 July 2022) and plants were monitored from 10 to 11 AM.	This App was used in two evaluation dates. In average the identification and diagnosis of disease/pest took 11 seconds (0,2 min). To use this App, the searching of image is manual and should be search in the list of insect, disease, fungus, and virus. Accord	Technician Handbooks
	BBCH-scale phenology stage recorded during the Smart application use on insect monitoring and data collection.	four evaluations were carried out and the BBCH corresponded (82), (802), (601, 631, 70, 701, 702, 703) two times with similar scale	BBCH scale 700	Technician Handbooks

3.2.1.2.3 General overview of mobile disorder detection for insect/disease in bell pepper crop monitoring in greenhouse

Bell peppers are primarily imported into Germany. Production of bell peppers in Germany is low. Its production is primarily in greenhouses where around 104 and 105 ha of land was dedicated to them in 2020 and 2021 respectively (BMEL 2022). It is still a widely consumed vegetable and the interest of growing them is increasing. Thus, to ensure its effective expansion of production, the growers need practical tools, which can help in monitoring pest/diseases during the crops growing cycle. Two smart applications, Plantix (an automatic image identification app) and Cropalyser (a manual app) were employed for pest/disease monitoring. The applications were evaluated according to the following parameters (Table 19):

Working speed: Plantix App took less time in the identification of pest/disease, while Cropalyser took around half a minute for identification. Cropalyser is an app that requires the name of the pest/disease to be searched manually before then comparing the pest/disease with the affected part of the plant. The application does not have automatic image identification like Plantix.

Acreage covered: Eight plants, replicated three times were monitored. The plants did not always display symptoms of pests/disease during evaluation but the plants that did were monitored using the apps.

Support from provider: Technical support from the provider/app developer was needed for both applications.

Mode of operation: Both applications were easy to use. Plantix has an option to select a crop to monitor, similar to Cropalyser. However, previous knowledge and training is needed for searching the list of pest/diseases when working with Cropalyser.

Accuracy: Both, applications were accurate, multiple high-quality images of pests/disease of helped when comparing potential pests/diseases. However, when working with Cropalyser, the user needs a knowledge of the pest/diseases of bell pepper in order to search the list and compare with the leaf and fruit.

Use-friendliness: for working with both applications, an internet connection is needed.

Phenological stage: Plantix app was employed three times, so in three BBCH scales, and Cropalyser employed once in one BBCH scale only.

3.2.1.2.4 General overview of mobile disorder detection for insect/disease cabbage crop monitoring in open field

Cabbage is a popular and well consumed vegetable in Germany. In 2021, around 434,87 tonnes of white cabbage were harvested in open fields across Germany. White cabbage is a variety of head cabbage and a vegetable that is grown in the autumn and winter season. To ensure its production, crop management and crop protection should be carried out. Nowadays there are smart technologies that can help during pest/diseases monitoring. Plantix and Cropalyser mobile smart applications were tested in tomato crop and were evaluated through the following parameters (Table 20):

Working speed: Plantix quickly identified caterpillars e.g., *Pieries brassicae* and *Spodoptera litura*. No diseases were seen during monitoring. However, Plantix could not recognise *Phyllotreta* spp. Cropalyser facilitated the recognition of *Phyllotreta* spp.

Acreage covered: The monitoring of cabbage plants was carried out in four plots. Two plots, where cabbage was planted as monocrop, and another two plots where cabbage was intercropped with wheat. The monitored plants of cabbage were part of a larger trial of cabbage plants infested with aphids. Monitoring plants without sensors was the purpose of this test of smart applications.

Support from provider: No technical support was needed during the usage of both applications.

Mode of operation: Both applications were easy to use. Plantix App has not the system for German version. In contrast, Cropalyser had not inconvenient to work in German. The monitoring using both applications was quick and worked well, permitting an internet connection was present. After being used with other vegetable crops, Cropalyser became familiar and therefore easy to use (Table 20).

Accuracy: Plantix App could recognize common caterpillars in cabbage such as *Pieris brassicae*. However, it could not identify the flea beetle *Phyllotreta* spp. Thus, Cropalyser was employed to search and compare from its data bank and list for this identification.

User-friendliness: Both applications were easy to use, and the pest/diseases of cabbage are included in their systems. If an English speaker is using Plantix then it is very user friendly, however it does not feature a German language setting.

Phenological stage: Plantix and Cropalyser Apps were used three times, during BBCH scale 17 to 24.

Table 19 – Mobile Disorder Detection for insect monitoring in bell pepper grown in greenhouse in Germany

Parameters	Questions	Plantix app	Cropalyser app	Traditional method
Working speed	Time to provide matched pictures on the disease/insect / plant	Identification of disease or pest with Plantix App need 7 to 11 seconds (0.1 - 0.2 min). The monitoring was in leaves and fruits.	This App was used two times, and monitoring of disease/pest took 30 seconds (0,5 min).	Technician Handbooks
	Were the insects / disease recognized by the Application and / traditional method?	Insects recognized: 1. Correct on leaf miner flies (Agromyzidae) Diseases recognized: 1. False positive on alfalfa mosaic virus 2. False positive on cucumber mosaic virus 3. False positive on bacterial spot pepper Physiological disorders (Fruits) 1. Correct on blossom end rot 2. Correct on Ca deficiency	This App monitored by manual comparison with picture and fruit. Disease recognized: False positive on leaf Anthracnose Physiological disorders Correct on Ca deficiency	Bell pepper: leaf miner flies (Agromyzidae) was seen in the leave and was either visible in some fruits to find Ca deficiency or blossom rot effect.
Acreage covered	How many plants/areas? Plants / Replicate	8 plants per replication were monitored. Sometimes, not all plants showed diseases or pest		Technician Handbooks
	How many insects / diseases were identified in the plant?	Sometimes, not all 8 plants did show diseases/pest. If so, one plant had from one to two insects or nothing, similar findings with diseases.	One to two disease/pest were recognized by manual comparison of pictures from data bank of the App.	Technician Handbooks
Support from provide	Free support? Y / N	Yes	Yes	Technician Handbooks
	Time in reacting from provider	Plantix App has a blog, and users can upload the picture and ask for recommendation or help.	The app is easy to use but needs internet connection. So, then is available the data bank with disease/pest list.	Technician Handbooks
	Paid to the central support?	support is free	We did not need for support.	Technician Handbooks
	Is quick enough the support? y/n	the App updates itself every two months, and system runs without inconvenient		Technician Handbooks
	Are the support materials free to download? y/n	Yes	Yes	Technician Handbooks
Mode of Operation	How long takes on average identifying the insect / disease (plant / s)? Discrepancies during tests?	it took between 7 to 11 seconds (0.1 - 0.2 min)	It took 0.5 min (30 s) for searching and finding the approximate name and picture in the list of fungus disease and physiological disorder.	Technician Handbooks
	How easy/complicated is the handling?	The use is not complicated, and the results can be sometimes one or three results. The user should have knowledge on pest/disease of bell pepper.	Is not complicate, but the user should have a previous knowledge on the disease/pest of bell pepper. The Apps provides good quality pictures to compare and facilitate the correct identification.	Technician Handbooks
	Is it available in your	is not available in German	Yes, is available in German version.	Technician

	language?			Handbooks
	Which operative system use Android or iOS?	<< Android system >>		Technician Handbooks
	Does this Application work with Data / Bluetooth / Wi-Fi?	Yes, the applications work with internet connected. Unfortunately, the App needs Wi-Fi connection or mobile Data from the telephone company	Yes, an internet connection is required or mobile telephone data.	Technician Handbooks
Accuracy	Do the Application provide a correct picture / correct identification on the insect/disease? y/n	Yes, e.g., leaf miner fly, Plantix App provides 3 pictures with good quality and recommendations to control from traditional to organic means. In fruits of bell pepper, the App could identify Blossom end rot that could help in bell pepper management.	Yes, but the user should have previous knowledge of pepper bell diseases/pest, so can compare the correct/approximate picture of disease/pest target. The results from other Apps were used to search and to match with the right disease/pest target.	Technician Handbooks
	Does the result match with Local Standard Method used?	Plantix App could recognize leaf miner, and it recommends from organic to chemical control.	A disease name with picture was found in the list with similar appearance of leaf with disease and was compared for getting recommendations.	Technician Handbooks
	Is it better / as good as / better than the traditional method?	Identification of diseases and pests with Plantix App helps in the diagnosis in Greenhouse for bell pepper.	Is good this App, but it needs a previous knowledge on disease/pest names of bell pepper.	Technician Handbooks
User-friendliness	INITIAL LAUNCH: Does the smart Application run at the beginning without difficult?	<< The Apps work with internet connection >>		Technician Handbooks
	DURING USAGE: Is the working process of the Application self-explanatory?	Yes, is self-explanatory, and bell pepper is included in the list of available plants for pest/diseases identification.	Bell pepper is included in the App, besides, disease, fungus, insects, virus to compare and recognize in the field or greenhouse.	Technician Handbooks
	Are the results clear and easy visualized?	Yes, the results are clear and easy through 3 pictures of good quality and the comparison option with the picture from the user.	Yes, 2 – 3 pictures with good quality of the disease/pest is provided to compare with the damaged leaf/fruit.	Technician Handbooks
Phenology Stage	When was the disease/pest identification collected by the Smart application from the vegetable?	Plantix App, was used four times (5, 11, 16, 26 July 2022) and plants were monitored from 10 to 11 AM.	This App was used two times.	Technician Handbooks
	BBCH-scale phenology stage recorded during the Smart application use on insect monitoring and data collection.	three evaluations were carried out and the BBCH corresponded (701/704), (701/705), (702/705)	This App was used once and was in the BBCH scale 700	Technician Handbooks

Table 20 – Mobile Disorder Detection for insect monitoring in cabbage crop grown in open field in Germany

Parameters	Questions	Plantix App	Cropalyser App	Traditional method
Working speed	Time to provide matched pictures on the disease/insect / plant	Plantix used 2 to 7 seconds (0.1 min). Cabbage plants in borders of plots were monitored.	Cropaliser App was used to confirm the identified pest/disease by previous Apps (Plantix or Xarvio Scouting). Thus, was easy to search in the list and find the disease/pest. Monitoring had 6 to 8 seconds (0.1 min).	Technician Handbooks
	Were the insects / disease recognized by the Application and / traditional method?	Insects recognized: 1. Correct on cabbage white butterfly (*Pieris brassicae*) 2. False positive on Spodoptera litura.	Cabbage crop did not report disease, pests only. Insect recognized: 1. Correct on crucifer flea beetle (*Phyllotreta* spp.) 2. Correct on cabbage white butterfly (*Pieris brassicae*) 3. Correct on cabbage white butterfly (*Pieris rapae*)	caterpillars from white butterfly (*Pieris brassicae*) , (Pieris rapae) were seen and little flea beetle (Phyllotreta spp) in the border of leaves.
Acreage covered	How many plants/areas? Plants / Replicate	The trial had four replications, each replication with 8 plants. Sometimes, not all plants reported diseases/pests.		Technician Handbooks
	How many insects / diseases were identified in the plant?	Sometimes, not all 8 plants had diseases/pest. In cabbage, the leaves were surveyed and if insects/worms were seen, they were identified.	Pest were monitored by manual comparison of pictures from data bank in the App.	Technician Handbooks
Support from provider	Free support? Y / N	<<< Yes >>>		Technician Handbooks
	Time in reacting from provider	No technical assistance was needed.	The app is easy to use, when previous knowledge on pest/diseases, but needs internet connection.	Technician Handbooks
	Paid to the central support?	Support is free	Not need support.	Technician Handbooks
	Is quick enough the support? y/n	The App has updated every two months, and when is updated the system runs without inconvenient		Technician Handbooks
	Are the support materials free to download? y/n	Yes, but is not available for German version.	Yes	Technician Handbooks
Mode of Operation	How long takes on average identifying the insect / disease (plant / s)? Discrepancies during tests?	2 to 7 seconds (0.1 min)	It took 0.1-0.2 min for searching the pest, following the insect species provided by the previous App output.	Technician Handbooks
	How easy/complicated is the handling?	The use is not complicated, and the results come out from one to three results appearing by importance order. However, the user should have knowledge on pest/disease of cabbage. Otherwise, it is advised to consult an expert.	Is not complicate, but, the user should have a previous knowledge on pests e.g., in cabbage. The App provides good quality pictures to compare and facilitate the correct identification.	Technician Handbooks
	Is it available in your language?	is not available in German	Yes, is available in German version.	Technician Handbooks
	Which operative system use Android or iOS?	<< Was installed in Android system >>		Technician Handbooks
	Does this Application work with Data / Bluetooth / Wi-Fi?	Yes, Plantix App needs an internet connection or Mobile Data.	Yes, an internet connection is required or mobile telephone data.	Technician Handbooks

Accuracy	Do the Application provide a correct picture / correct identification on the insect/disease? y/n	Plantix App provided correct picture after identification with two or three pictures and the user can compare with the submitted picture. The app recognized caterpillars like Cabbage white butterfly (*Pieris brassicae*). However, Flea beetles (*Phyllotreta spp*.), was not identified, and seems is not in the data bank.	It depends on user knowledge and matching the approximate picture of disease/pest target. By instance, results from other Apps were used to search and to match with the right disease/pest target.	Technician Handbooks
	Does the result match with traditional method used?	E.g., cabbage white butterfly (*Pieris brassicae*), it matched and was consulted with cabbage cultivation book and a colleague. But, this App did not identify *Phyllotreta spp.*	E.g., a little beetle as *Phyllotreta spp*. was not identified by the previous Apps. With pictures and searching in list of "Insects" was selected and compared from Cropalyser.	Technician Handbooks
	Is it better / as good as / better than the traditional method?	Yes, is better, but it did not recognize *Phyllotreta sp*.	Yes, was adequate to search and compare manually for *Phyllotreta spp*.	Technician Handbooks
User-friendliness	INITIAL LAUNCH: Does the smart Application run at the beginning without difficult?	Yes, Plantix App runs smoothly.	As new user, you must search and select the crop and again select the pest/disease list.	Technician Handbooks
	DURING USAGE: Is the working process of the Application self-explanatory?	Yes, the use and options to select for any crop are easy to use and clearly explained.	The app has a list of known vegetable crops and includes cabbage, and has a list of disease, fungus, insects, virus that helps for comparing and recognizing in the field or greenhouse.	Technician Handbooks
	Are the results clear and easy visualized?	Yes, the results are clear and easy through 3 pictures of good quality and compared during pest/disease monitoring.	Yes, two or three pictures with good quality of the pest are provided to compare in the field/plot/greenhouse.	Technician Handbooks
Phenology Stage	When was the disease/pest identification collected by the Smart application from the vegetable?	Plantix App, was used three times (July and August 2022) and plants were monitored from 06:30 to 08:30 AM.	Cropalyser App, was used three times (13 July, 17 and 24 August 2022) and plants were monitored from 06:30 to 08:30 AM.	Technician Handbooks
	BBCH-scale phenology stage recorded during the Smart application use on insect monitoring and data collection.	This App, was used during BBCH scale 17 to 24	This App was used during BBCH scale 17 to 24	Technician Handbooks

3.3 Decision support group

3.3.1 'Without sensors' sub-group

3.3.1.1 Testing mobile decision non-sensors in Belgium

Ensuring good production and yield means an appropriate crop management and protection strategy. Both vegetable crops grown under greenhouse and open fields require this. Traditional methods in crop monitoring, are still based on technical knowledge, handbooks on pest/diseases and laboratory analysis. However, in the last five years, new tools based on artificial intelligence, algorithms and data bases with many pictures to provide results in a smart application have been developed. These applications can be installed on tosmartphones or tablets and in some cases do not require sensor. Thesecan help in pest/disease monitoring but often require internet connection.

Three smart applications for vegetable crop monitoring of pest/diseases were tested (Table 21) on lettuce, cabbage, Brussels sprouts, and leeks grown in greenhouse and open field settings.

Table 21 – Trial description for the smart applications used in vegetable crops monitoring in Belgium

Trial Name	**lettuce, white cabbage, Brussels sprouts, and leek**
Trial Location	Ieperseweg 87 8800 Roeselare, Belgium
Trial type	Greenhouse / open field
Replicates	5 (only 3 for Brussel Sprouts) Xarvio Scouting (n = 5) Agrio app (n = 5) Bioline app (n = 5)
Additional Information	Lettuce: 30 × 30 cm Cabbage: 50 × 70 cm Brussels sprouts: 43 × 70 cm Leek: 9 × 70 cm

3.3.1.1.1 General overview of technologies without sensors for pest/disease monitoring in leafy vegetable crops in Belgium

Leafy vegetable crops () are popular and well consumed by the Belgian population. Ensuring good production and yield of these crops in an IPM system requires the use of practical methods in crop monitoring against pest/diseases. Three smart applications without sensors were employed for monitoring pest/diseases (Table 22) and their performance was evaluated according to following parameters:

Working speed: From the three applications, only two were employed. Xarvio Scouting App and Agrio Technology app were tested for pest/diseases monitoring. Bioline App was not working at the time of whene the test was carried out. Both applications took a similar amount of time to identify potential pests/diseases, and this was quicker when comparing with the traditional manual method of identification.

Acreage covered: between three to five plants were monitored. Xarvio Scouting does not have lettuce in its list of crops, and leek is not included in the Agrio app.

Support from provider: technical assistance from providers was not tested.

Mode of operation: Both applications took a similar time for pest/disease monitoring. Their usage is quite intuitive, but the user should have a previous knowledge of pest/diseases of vegetable crops. Xarvio Scouting is available in Dutch, however Agrio app is not. Both applications were installed on Android and iOS and worked with mobile data.

Accuracy: Both applications could not provide a correct identification of the pest/diseases of the monitored vegetable crops.

User-friendliness: Xarvio Scouting and Agrio apps required the user to download data and after they were operatable. The handling of both applications was quite intuitive, and they were easy to use.

Phenological stage: Both applications were used in two stages of BBCH scale.

Table 22 – Overall evaluation of smart application without sensors used in four vegetable crops in Belgium

Parameters	Questions	Xarvio Scouting App	Agrio Technology App	Bioline App	Traditional method = field scouting expert
Working speed	Time to provide matched pictures on the disease/insect	0.3 min (20 s)	0.3 min (20 s)	Not working anymore	0.1 min (6 s)
	Were the insects/diseases recognized by the Application and / or traditional method?	Lettuce: not supported White cabbage: false positive *Alternaria brassicae* Brussels Sprouts: false positive Aphids Leek: false positive on *Oulema melanopus, Pleospora allii. Correct on thrips*	Lettuce: false positive on flower thrips, suggested downy mildew White cabbage: false positive *Alternaria brassicae* Brussels Sprouts: false positive Aphids Leek: not supported		Lettuce: Downy mildew White cabbage: *Mycosphaerella brassicicola*, *Alternaria brassicae* Brussels Sprouts: *Aleyrodres proletella* Leek: *Puccinia allii*, thrips
Acreage covered	How many plants/area?	3 – 5	3 – 5		3 – 5
	How many insects / diseases were identified in the plant?	Lettuce: not supported White cabbage: false positive *Alternaria brassicae* Brussels Sprouts: false positive Aphids Leek: false positive on *Oulema melanopus*, *Pleospora allii*. Correct on thrips	Lettuce: false positive on flower thrips, suggested downy mildew White cabbage: false positive *Alternaria brassicae* Brussels Sprouts: false positive Aphids Leek: not supported		Lettuce: Downy mildew White cabbage: *Mycosphaerella brassicicola*, *Alternaria brassicae* Brussels Sprouts: *Aleyrodres proletella* Leek: *Puccinia allii*, thrips
Support from provider/	Free support? Y / N	not tested	not tested		not applicable
	Time for provider's response	not tested	not tested		not applicable
	Does it need a payment to Central support?	0	Basic: €4,39/month Pro: €39,99/month		not applicable
	Is the support quick enough? y/n	not tested	not tested		not applicable
	Are the supporting materials free to download? y/n	Yes, Dutch version	Yes		not applicable
Mode of Operation	How long does it take on average identifying the insect / disease (plant / min)? Discrepancies during tests?	0.3 min (20 s)	0.3 min (20 s)		not applicable
	How easy/complicated is the handling?	The handling is quite intuitive Easy: score 9/10	The handling is quite intuitive Easy: score 8/10		not applicable
	Is a Smart application available in your language?	Yes, Dutch version	No, English		not applicable
	Which operating system does it use, Android or iOS (Iphone / Ipad)?	Android / iOS	Android / iOS		not applicable
	Does this Application work with Mobile Data / Bluetooth / Wi-Fi	Mobile data	Mobile data		not applicable
Accuracy	Does the Applications provide a correct picture / correct identification on the insect/disease? y/n	Lettuce: not supported White cabbage: false positive *Alternaria brassicae* Brussels Sprouts: false positive Aphids Leek: false positive on *Oulema melanopus*, *Pleospora allii*. Correct on thrips	Lettuce: false positive on flower thrips, suggested downy mildew White cabbage: false positive *Alternaria brassicae* Brussels Sprouts: false positive Aphids Leek: not supported		not applicable

	Does the result match with the traditional method used?	Lettuce: not supported White cabbage: false positive *Alternaria brassicae* Brussels Sprouts: false positive Aphids Leek: false positive on *Oulema melanopus*, *Pleospora allii*. Correct on thrips	Lettuce: false positive on flower thrips, suggested downy mildew White cabbage: false positive *Alternaria brassicae* Brussels Sprouts: false positive Aphids Leek: not supported	not applicable
	Is it better / as good as / better than the traditional method?	Not better	Not better	not applicable
User-friendliness	INITIAL LAUNCH: Does the smart Application run from the beginning without difficulty? Does the smart application require Wi-Fi/Mobile Data/Internet.	Data needed to download and operate	Data needed to download and operate	not applicable
	DURING USAGE: Does the working process of the Application is self-explanatory?	The handling is quite intuitive Easy: score 9/10	The handling is quite intuitive Easy: score 8/10	not applicable
	Are the results clear and easy visualized?	Yes: score 9/10	Yes: score 8/10	not applicable
Phenological Stage	Date and hour when the Smart Application was used	2/01/2023 afternoon 3/01/2023 afternoon	2/01/2023 afternoon 3/01/2023 afternoon	2/01/2023 afternoon 3/01/2023 afternoon
	BBCH-scale phenology stage when the Smart Application was used to identify insect / disease	See regular evaluation	See regular evaluation	See regular evaluation

3.3.1.2 Testing mobile decision non-sensors in Germany

Automatic, image-based pest/disease recognition as well as a large database application were employed to aid in pest and disease monitoring in greenhouse and open field vegetable systems in Germany. The use of these technologies can in decision support helping with the management ofpests and disease. Xarvio Scouting, Agrio and Bioline applications were employed to monitor pest and diseases in cucumber, tomato, bell pepper and cabbage in July and August of 2022 (Table 23).

Table 23 – Trial description for technologies without sensors in cucumber, tomato, bell pepper and cabbage in Germany

Trial Name	Cucumber	Tomato	Bell pepper	Cabbage
Trial Location	Braunschweig, JKI	Braunschweig, JKI	Braunschweig, JKI	Hotzum, Exp. Field, Braunschweig, JKI
Trial Area (m²)	12	12	20	4000
Trial type	Greenhouse – room	Greenhouse - room	Greenhouse - room	Open Field
Replicates	Three replicates (a, b, c): - Xarvio Scouting App	Three replicates (a, b, c): - Xarvio Scouting App, Agrio App and Bioline App	Three replicates (a, b, c) - Xarvio Scouting App	Four replicates (a, b, c, d) - Xarvio Scouting App and Agrio App
Additional Information	Glasshouse Monitoring: July month, Temperature: 22°C RH (%): 56.5 Soil texture: loamy Cucumber planted in three rows, distance between rows = 1 m Plant distances = 0.4 m	Glasshouse Monitoring: July month, Temperature: 22°C RH (%): 56.5 Soil texture: loamy Tomato planted in three rows, distance between rows = 1 m Plant distance = 0.4 m	Glasshouse Monitoring: July month Temperature: 20 – 22°C RH (%): 56.5 Sweet Pepper var. Bendigo F1/Enza Zaden Substrate: Clay Substrate distance between rows = 1 m Plant distance = 0.5 m	Open field Monitoring: July and August Field Temperature: 9 – 28°C RH (%): 20 – 60% Soil Texture: clay loamy row intercropping (cabbage/wheat) and row monocrop (cabbage) plants rows distance = 0,5 m Cabbage plants distance = 0,4 m Two types of plots: A) intercropping (cabbage/wheat), and B) monocropping (cabbage)
Trial overview	Monitored 8 plants per replication (n = 8; a, b, c) Recorded BBCH scale of phenology. Plants evaluated weekly in July 2022.	Monitored 8 plants per replication (n = 8; a, b, c) Recorded BBCH scale of phenology. Plants evaluated weekly in July 2022.	Monitored 8 plants per replication (n = 8; a, b, c) Monitored plants without covering with Apps on disease/pests. Recorded BBCH scale of phenology.	Monitored 8 plants per replication in borders of selected experimental units (plots). Three times in July and August months. Surveyed two replications for monocrop (cabbage) and two for intercrop (cabbage/wheat) with mobile Apps.

3.3.1.2.1 General overview of technologies without sensors for pest/disease monitoring in leafy vegetable crops in Germany

The Cucurbitaceae, Solanaceae and Brassicaceae vegetables of cucumber, tomato, bell pepper and cabbage were monitored for pest/diseases with mobile application technologies without sensors (Table 24). In previous sections, specific smart applications were employed for plant protection. For the same plants, smart applications were used to monitor and identify pest and diseases. These smart application technologies and their performance was evaluated according to following parameters:

Working speed: Xarvio Scouting App was tested in cucumber, tomato and bell peppers grown in greenhouses and cabbage crops grown in open field. Time for identifying pest and disease was short, however the results from the app on the vegetable crops is just the name of the disease/pest. The recommendations for the control are provided via a link to the website of the company, where the user can then select products ranging from chemical to organic for treatment application. Disease and pests recognized by the Xarvio Scouting App were the same as the ones identified by the Plantix App.

Acreage covered: eight plants were monitored, sometimes not all of the plants had leaves or fruit with pest/disease.

Support from provider: No technical assistance or support was needed during monitoring of pest/diseases. Materials are available on their website that can help, however, before using Xarvio Scouting you must read the introductory page to gain a good understanding as the application can perform other calculations that may be of use.

Mode of operation: Xarvio Scouting has a German version available, the smartphone or tablet should be connected to the internet or have mobile data access to use the identification function. It was not difficult to work with the application, its operation is intuitive. Xarvio Scouting has other functions such as identifying the nitrogen status of the crop or counting the number of insects trapped on a yellow sticky plate. The results are very brief, and after confirmation by the user that the app is correct on its assessment, the application provides a link to the company's website to select products for purchasing.

Accuracy: between two to three diseases were recognized in the cucumber, tomato and bell pepper crops by the Xarvio Scouting App.

User-friendliness: After initial set up and connection to the internet the application is easy to use, there is a list of vegetable crops, thus, the preferred crops were selected, and the application has the GPS localizer. The results show one image of the potential pest and disease, and the user must confirm if it is correct, the application then provides the full name of the pest/disease.

Phenological stage: The application was used four times in cucumber, tomato, and bell pepper, whereas for cabbage, the monitoring was performed only three times. BBCH scales were used to record the phenological stages of the crop vegetables.

3.3.1.2.2 General overview of technologies without sensors for pest/disease monitoring in vegetable crops in Germany

Tomato and cabbage are important vegetables in Germany, cabbage is widely produced domestically in the open field whereas tomato is largely imported, and the small amount of growing is done in greenhouses. Previously in this report, smart applications were utilized for monitoring pest and diseases in both of these systems in Germany. There are however other kinds of applications that can also help for pest/disease monitoring. Agrio App and Bioline App (an application with similar features to the Cropalyser App) were employed for the monitoring of pest and diseases in tomato and cabbage. Three smart applications without sensors were employed for monitoring pest and diseases (Table 25), and the performance were evaluated according to following parameters:

Working speed: In tomato, Agrio app and Bioline app were employed. Agrio App was quick, and the tomato crop is included in its library. Agrio recognized many of the pest and diseases similar to Plantix. It did however wrongly identify *Tuta absoluta*. Bioline was used to search i's database for leaf miner, which aided in identifying the same species as Plantix did. The Agrio app was used in cabbage to find out about *Phyllotreta spp* and *Pieris brassicae* that were correct.

Acreage covered: both applications were tested in eight plants with three and four replications of tomato and cabbage respectivley. Sometimes not all plants displayed signs of disease/pests.

Support from provider was not needed, although the Bioline App was sometimes slow when browsing the list. The applications were only used by their free versions.

Mode of operation: The applications identified the pest and disease between around 6 – 7 seconds, for tomato and cabbage this was not complicated as both crops are included in the list of supported vegetables in the Agrio and Bioline apps. Bioline is not available in the German language, the Agrio App, was usable in German. Both applications required internet connection to work.

Accuracy: Agrio App provides two pictures with good quality that helps to ensure that the diagnosis and the results of the pest/disease is correct. The recommendations range from practices to control. In contrast, the Bioline App helps in the description of the pest, in this case of the leaf miner, the app did not provide a good quality image of the pest. Bioline provides good recommendations for applying products from biological control like parasitoids or biological funga control control only (Table 25).

User-friendliness: Connected to the internet or mobile data, the applications run smoothly in free version. Sometimes, commercial advertisements appear in the Agrio App. Bioline sometimes runs slowly, perhaps due to application maintenance. During the usage it is quite intuitive, in Agrio, the user should fill out a questionnaire about the crop during the monitoring process to ensure more precise results.

Phenological stage: Agrio app was used in the last evaluation of tomato (BBCH 700) and Bioline app either (BBCH 700), and in cabbage, one evaluation only (BBCH 24).

Table 24 – Overall evaluation of smart application without sensors used in four vegetable crops in Germany

Parameters	Questions	Xarvio Scouting App – Cucumber	Xarvio Scouting App – Tomato	Xarvio Scouting App – Bell pepper	Xarvio Scouting App – Cabbage	Traditional method
Working speed	Time to provide matched pictures on the disease/insect / plant	5 to 18 seconds, if internet is weak, the app will run slowly, and the results will take time.	7 to 13 seconds, if internet is weak, the app runs slowly, and the results will take time.	7 to 27 seconds (0.1 - 0.5 min), if the internet is weak, the app runs slowly, and processing image will take time.	7 to 9 seconds (0.1 min), if the internet is weak, the app runs slowly, and results will take time.	Technician Handbooks
	Were the insects / disease recognized by the Application and / or traditional method?	Insects recognized: 1. Correct on spider mites 2. False-positive on leaf miner flies (Agromyzidae) 3. False-positive on thrips (not sure) Diseases recognized: 1. Correct on downy mildew (*Pseudoperonospora cubensis*) 2. False-positive on powdery mildew (Erysiphaceae) 3. False-positive on powdery mildew (*Pedosphaera xanthii*), not sure	Insects recognized: 1. False-positive on spider mites (Tetranychidae) 2. Correct on leaf miner flies (Agromyzidae) 3. False-positive on tomato leaf miner (*Tuta absoluta*) 4. False-positive on thrips (not sure) Diseases recognized: 1. Correct on powdery mildew (Erysiphaceae) 2. False-positive on powdery mildew (*Oidium neolycopersici*) 3. False-positive on tomato late blight Physiological disorders 1. Correct on Mg deficiency 2. Correct on leaf curly	Insects recognized: 1. Correct on leaf miner flies (Agromyzidae) Diseases recognized: 1. False-positive on cucumber mosaic virus (cannot be sure) 2. False-positive on alfalfa mosaic virus (not sure) Physiological disorder (Fruit) 1. Correct on Ca deficiency	Insects recognized: 1. False-positive on Aphids 2. Correct on *Pieris brassicae*	Cucumber: was visible spider mites in some plants and downy mildew. Tomato: leaf miner flies (Agromyzidae). Powdery mildew (Erysiphaceae) and the colour spots in leaves due to Mg deficiency. Curly leaves was seen, and it would be needing a verification whether is virus or another physiological disorder or water stress. Bell pepper: leaf miner flies (Agromyzidae) was seen in the leave and was visiilble in some fruits to find Ca deficiency or blossom rot effect. Cabbage: caterpillars (*Pieris brassicae*) were seen and little flea beetles (*Phyllotreta spp*.) in the border of leaves
Acreage covered	How many plants/area? Plants / Replicate	<<< 8 plants per replication were monitored. Sometimes, not all plants showed diseases or pest >>>				Technician Handbooks
	How many insects / diseases were identified in the plant?	Sometimes one or two pests could be identified. it needed a good and correct picture to facilitate the identification by the App.				Technician Handbooks
Support from provider	Free support? Y / N	no	no	no	no	Technician Handbooks
	Time in reacting from provider	The app worked without problems. However, when the user has a premium subscription, a technician can provide technical support on disease and pests.				Technician Handbooks
	Paid to the central support?	<<< support is free, but products should be purchased >>>				Technician Handbooks
	Is quick enough the support? y/n	the App has updated every two months, and when is updated the system runs without inconvenient				Technician Handbooks
	Are the support materials free to download? y/n	<<<<< Yes >>>>>				Technician Handbooks
Mode of Operation	How long takes on average identifying the insect / disease (plant / s)? Discrepancies during tests?	5 to 18 s	7 to 13 s	7 to 27 s	6 to 9 s	Technician Handbooks
	How easy/complicated is the handling?	Using this App is not complicated - however, the result gives only the name and after confirmation, the App provides a link of list products to use for controlling disease/pest.				Technician Handbooks

	Is it available in your language?	<<< Available in German version and other languages >>> .			Technician Handbooks
	Which operative system use Android or iOS.	Android			Technician Handbooks
	Does this Application work with Data / Bluetooth / Wi-Fi?	<<< Yes, the applications need internet connection or mobile Data from the telefon company >>>			Technician Handbooks
Accuracy	Do the Application provide a correct picture / correct identification on the insect/disease? y/n	Xarvio Scouting App provided between one to two possible disease/pest as diagnosed in the leaf/fruit. After that the user should confirm, of course should have previous knowledge on pest and disease of monitored vegetable crop, and the app provides the products to apply with the link of website to purchase from chemical to organic products.		Xarvio Scouting App provides between one or two results to confirm and with one picture, e.g., Cabbage white butterfly (*Pieris brassicae*). The correct pest was Cabbage white butterfly. The user should have knowledge on pest for Cabbage crop.	Technician Handbooks
	Does the result match with Local Standard Method used?	The description from the Results on the disease / pest is very short with the scientific name. After confirmation by the user. The App provides link to the website for choosing technical assistance or purchasing the products from the company.		Yes, the identification of Cabbage white butterfly *(Pieris brassicae*) matched with the handbook and the manual App Cropalyser.	Technician Handbooks
	Is it better / as good as / better than the traditional method?	>>> Is not good, in this version of free use, when the App recommends connecting to the company and purchase the products. <<<			Technician Handbooks
User-friendliness	INITIAL LAUNCH: Does the smart Application run at the beginning without difficult?	Yes, the application runs smoothly when the smartphone is connected to internet or mobile data. Without internet, the application does not work.			Technician Handbooks
	DURING USAGE: Is the working process of the Application self-explanatory?	Xarvio Scouting App has other options for not only identification of pest/disease, but for fertilization of plant status, identification of weeds, count of insects in traps. However, for monitoring pest/diseases, the results are linked with product purchase.			Technician Handbooks
	Are the results clear and easy visualized?	Xarvio Scouting App provides only one picture but does not have the option to compare with the target picture taken in field or greenhouse.			Technician Handbooks
Phenology Stage	Date and hour when the Smart Application was used	Xarvio Scouting App, was used four times (5, 11, 16, 26 July 2022) and plants were monitored from 10 to 11 AM (cucumber), 11 to 1 AM (tomato), 9 – 10 AM (bell pepper).		App was used three times (13 July, 17 and 24 August 2022) and monitored from 06:30 to 08:30 AM.	Technician Handbooks
	BBCH-scale phenology stage when the Smart Application was used to identify insect / disease	four evaluations when BBCH corresponded (82), (802), (601, 631, 70, 701, 702, 703) two times with similar scale	four evaluations when BBCH corresponded (82), (802), (601, 631, 70, 701, 702, 703) two times with similar scale	four evaluations when BBCH corresponded (700), (701/704), (701/705), (702/705)	This App was used three times during BBCH scale 17 to 24	Technician Handbooks

Table 25 – Overall evaluation of smart application without sensors used in two vegetable crops in Germany

Parameters	Questions	Agrio App – Tomato	Bioline App – Tomato	Agrio App – Cabbage	Traditional method
Working speed	Time to provide matched pictures on the disease/insect / plant	6 seconds, if internet connection is not good, the identification will take more time or will not work.	7 seconds, it was used in the last evaluation only. This app works like Cropalyser and works only for insects and recommends using biologic products.	The identification took 6-7 seconds (0.1 min).	Technician Handbooks
	Were the insects / disease recognized by the Application and / or traditional method?	Insects recognized: 1. False-positive on leaf miner (*Tuta absoluta*) Diseases recognized: 1. False-positive on tomato late blight 2. Correct on powdery mildew Physiological disorder recognized: 1. False-positive on water stress 2. Correct on Mg deficiency	One insect was found in the data bank or list for tomato crop: Leaf miner.	Insects recognized: 1. False-positive on Oedem (Edema) 2. False-positive on Cotton Leaf Worm (*Spodoptera litura*) (cannot be in Germany) 3. Correct on cabbage white butterfly (*Pieris brassicae*) 4. Correct on flea beetle (*Phyllotreta* spp.)	Tomato: leaf miner flies (Agromyzidae). Powdery mildew (Erysiphaceae) and the colour spots in leaves due to Mg deficiency. Curly leaves was seen, and it would be needing a verification whether is virus or another physiological disorder. Cabbage: caterpillars (*Pieris brassicae*) were seen and little flea beetles (*Phyllotreta spp.*) in the border of leaves
Acreage covered	How many plants/area? Plants / Replicate	8 plants per replicate (a, b, c).	8 plants per replicate (a, b, c). Sometimes, not all plants reported diseases/pests.	8 plants per replication (a, b, c, d) monitored. Sometimes, not all plants had pests.	Technician Handbooks
	How many insects / diseases were identified in the plant?	Each plant had sometimes one or two disease/pest.	Only one pest was recognized as leaf miner. This insect is in the list of pests.	Sometimes one or two pests could be identified, but wrong.	Technician Handbooks
Support from provider	Free support? Y / N	yes	yes	Yes, with limitations, although with subscription the support is better.	Technician Handbooks
	Time in reacting from provider / hours / minutes / day.	Was not needed	The App works as a field book, the user can register information from field. Support can be got through email.	The app worked without problems. However, with a premium subscription, a technician can provide support/advice on the pest/disease.	Technician Handbooks
	Paid to the central support?	Free version was used, although there is the option to purchase a subscription.	support is free; however, products should be purchased	Support is free	Technician Handbooks
	Is quick enough the support? y/n	Yes	we did not have inconvenient during our evaluation.		Technician Handbooks
	Are the support materials free to download? y/n	Yes	Is free	Yes	Technician Handbooks
Mode of Operation	How long takes on average identifying the insect / disease (plant / min)? Discrepancies during tests?	Agrio App identified in 6 seconds.	In the list of pests for tomato, there was Leaf Miner only, which was compared. Results from other apps to correlate the result were used. In time for searching, it took 0.2 - 0.4 minutes as beginner.	6 to 7 s (0.1 min)	Technician Handbooks

	How easy/complicated is the handling?	Easy, sometimes, advertisement annoys the use when disease/pest needs to be recognized.	Is not complicate, however, the list of pests was not many for tomato	Agrio App request to select the vegetable crop for the identification, then, ask some questions about crop management, then, the App start to work with identification.	Technician Handbooks
	Is it available in your language?	Available in many languages, but not for German version.	No, only in English, French, Spanish	Not available in German version.	Technician Handbooks
	Which operative system use Android or iOS	<<< Android >>>			Technician Handbooks
	Does this Application work with Data / Bluetooth / Wi-Fi?	<<< Yes, the App needs an internet connection or mobile data. >>>			Technician Handbooks
Accuracy	Do the Application provide a correct picture / correct identification on the insect/disease? y/n	Only two correct identifications were recognized as powdery mildew and Mg deficiency.	The App provides only one picture for Leaf Miner. Nevertheless, had a good description for applying biological control.	Agrio App provided a correct identification for *Phyllotreta* spp. But for the catterpillars, the output was "moths" with low confidence.	Technician Handbooks
	Does the result match with traditional method used?	Insect recognized 1. False-positive on leaf miner (*Tuta absoluta*) (wrong) Diseases recognized: 1. False-positive on tomato late blight 2. Correct on powdery mildew Physiological disorder: 1. False-positive on water stress 2. Correct on Mg deficiency	With only one picture and the description, was fine. Nevertheless, for the next steps for biological control the App provide link for purchasing products.	Yes, the identification and the correct name for Flea beetle (spp.) was close with the picture, and compared with the results of Cropalyser App.	Technician Handbooks
	Is it better / as good as / better than the traditional method?	The user of the App should have knowledge on Agricultural Entomology and Phytopathology. It can help to recognize.	We only used and found out Leaf Miner, and for one pest, is not enough.	Is good, but with the question before the identification, makes you spend time.	Technician Handbooks
User-friendliness	INITIAL LAUNCH: Does the smart Application run at the beginning without difficult?	Connected to the internet, the App runs smoothly, but sometimes Commercial Adds show up, which is a little bit annoying.	The app works connected to internet.	Works, but advertisements appear often, which make a little hard to use after.	Technician Handbooks
	DURING USAGE: Is the working process of the Application self-explanatory?	The procedure is easy and accept all the questions made by the App.	The app has not many vegetable crops to choose. We found tomato and, in the list, we found Leaf miner.	Not very easy, at least you need to know the options and what to select in case of vegetable crop to be identified.	Technician Handbooks
	Are the results clear and easy visualized?	The App provides two pictures with good quality and the description for the control.	The description of the pest is clear, but only one picture.	Agrio App provides a sort of identified pest according to high score. It means high score is high confidence and low score with less probability.	Technician Handbooks
Phenology Stage	Date and hour when the Smart Application was used	This App was used in one evaluation only and was the last date. The purpose to use was to compare whether the other Apps were correct.	This app was used in the last evaluation. The purpose was to corroborate identification of Leaf Miner.	Agrio App, was used only once time (24 August 2022) from 06:30 to 08:30 AM.	Technician Handbooks
	BBCH-scale phenology stage recorded	The App was used in the last evaluation.	BBCH scale 700	This App was used once during BBCH scale 24	Technician Handbooks

4 Summarized outcomes

Smart traps, mobile applications and non-sensor applications were tested in the last season of 2022 on vegetable crops in different countries by the project partners. The testing of the technologies was carried out on vegetables growing in both greenhouse and open field systems. The purpose was to determinate the effectiveness of these technologies in terms of their working speed, acreage covered, mode of operation and accuracy for the monitoring and identification of pest and diseases in different crops, growing settings and places.

a) 'Monitoring' technologies group:

a.1) The '*Insect monitoring*' sub-group selected technologies using camera systems to detect insects-based image data bank and algorithms were employed to test on vegetable crops. The main camera-based systems were Trapview, iScout, CapTrap (Table 26). Target insects in carrot, brassic (e.g., cauliflower) and tomato were recognized by the Trapview trap by its camera and algorithms. Whilethe Captrap trap captured many insects but did not recognize the diamond black moth (*Plutella xylostella*) in Belgium and the United Kingdom. In Latvia, there was no reported diamond black moth, but the Captrap trap captured other insects. The iScout trap captured many insects, but not the target insects. The system provides the possibility **to remotely identify and mark the insects.**

Table 26 – Evaluated smart traps to monitoring insects in vegetable crops

Technology group and sub-group	Technology	Target crop	Target pest	Recognized insects by smart trap
Monitoring	Trapview	Carrot	Carrot fly	No [LVA], [UK]
		Brassica	Diamond-back moth	Yes [BE], Yes [LVA], Yes [UK]
Insect		Tomato	Tomato leaf miner	Yes [PT], Yes [UK]
	CapTrap	Brassica	Diamond-back moth	Not [BE], [UK], [LVA]
	iScout	Cabbage	Diamond-back moth	Not [BE], [UK]

BE: Belgium, ES: Spain, LVA: Latvia, PT: Portugal, UK: United Kingdom, carrot fly (*Chamaepsila rosae*), Diamond-back moth (*Plutella xylostella*), Tomato leaf miner (*Tuta absoluta*)

b) Diagnosis and detection group:

b.1) The '*Disorder detection using mobile phone*' technologies sub-group selected **Plantix and Cropalyser** to be used in the demo trials during the 2022 season. The applications are available in Europe and can be used in greenhouses and in open field production systems. Two smart applications were used, the Plantix and Cropalyser Apps (Table 27). The Plantix App works by automatic AI image identification of an uploaded image of problem area. Target pests of vegetable crops such as cucumber, tomato, bell pepper and cabbage were tested using the Plantix app. The App could recognise spider mites in cucumber crops grown ingreenhouses, leaf miner in tomatoes grown in greenhouse, it could also identifydeficiency of Ca in bell peppers grown in greenhouses. However, in the open field for the cabbage, there was visible presence of flea beetles in the leaves, and Plantix App could not recognize this beetle. It seems that this insect is not included in its image data base.

Evaluation with Cropalyser took time to use for the identification of pest in cucumber, tomato, bell pepper and cabbage, because the procedure is manual. The application does not provide pictures, and the probable disease or pest must be searched in the list of vegetable crops in the menu inside of the application. In the first attempt, we searched the name and according to our knowledge we found the name of pest or disease, or we used the name of pest or disease from the output of other application to verify. So, in that case it was relatively quick to use. Flea beetle was not recognized

by Plantix, but according to the list of pests in cabbage, we found the picture and the description of the insect *Phyllotreta* spp., in that situation, Cropalyser was useful, because the name from other apps result guided for searching and use it.

Table 27 – Evaluated smart applications to monitoring pest and diseases in vegetable crops

Technology group	Technology sub-group	Technology	Target crop	Target pest	Recognized pest and diseases by smart Apps
Diagnosis and detection	**Disorder detection mobile Apps**	Plantix App	Cucumber	Spider mites	Yes [DE]
			Tomato	Leaf miner fly	Yes [DE], [ES]
			Bell pepper	Ca deficiency	Yes [DE]
			Cabbage	Flea beetle	Not [DE]
		Cropalyser App	Tomato,	Leaf miner fly	Yes [DE]
			Cucumber	Spider mites	Yes [DE]
			Bell pepper	Leaf miner fly	Not [DE]
			Cabbage	Flea beetles	Yes [DE]

DE: Germany, ES: Spain

c) Decision support group:

c.1) The '*Decision support (no sensors)*' sub-group selected the **Xarvio scouting** App due to its applicability in open field crop cultivation and because it can identify other parameters of the plants such as nitrogen status, number of captured insects on yellow sticky traps, number of seedlings and of course monitoring disease and pests in the field. The App - **Agrio Technology** could be used on all the target crops except for leeks. The **Bioline** App was available only for tomato and for the leaf miner fly (Table 27).

Xarvio Scouting App could recognize disease and pests in many vegetable crops, but not all crops are listed in its menu such as lettuce. Specific and known pests and disease were recognized for tomato, cucumber, cabbage and bell pepper, but not for lettuce and Brussel sprouts. Agrio App could recognise powdery mildew in tomato and flea beetle in cabbage. In contrast, for vegetables such as lettuce, white cabbage and Brussel sprouts it could not identify and was wrong. Further, leek vegetable crop is not included in its list and does not provide support on it. Bioline App was used to test insects, this manual and field book application has a list of crops including tomato. The application has many insects in its databse and was used to find further information on leaf miners for tomatoes. The Bioline App was unusable for vegetable crops in Belgium, possibly due to it requiring maintenance.

Table 28 – Evaluated technologies without sensors to monitoring pest and diseases in vegetable crops

Technology group and sub-group	Technology	Target crop	Target pest	Recognized pest and diseases by smart Apps
Decision support	Xarvio Scouting App	Tomato	Leaf miner fly	Yes [DE]; [ES]
		Lettuce, Brussel sprouts, white cabbage	Lettuce (not supported)	Not [BE]
		Leek	*Oulema melanopus, Pleospora allii*	Not [BE]; Yes [BE] in thrips
Without sensors		Cucumber	Spider mite, powdery mildew	Yes [DE]; [ES]
		Bell pepper	Leaf miner fly	Yes [DE]
		Cabbage	Cabbage white butterfly	Yes [DE]
	Agrio App	Tomato, Cabbage	Powdery mildew, Flea beetle	Yes [DE]
		Lettuce, Brussel sprouts, white cabbage	Lettuce: false positive on flower thrips, suggested downy mildew White cabbage: false positive on Alternaria brassicae Brussels Sprouts: false positive on Aphids	Not [BE]
		Leek	Leek (not supported)	Not [BE]
	Bioline App	Tomato	Leaf miner fly	Yes [DE];
		Lettuce, Brussel sprouts, white cabbage, leek		Not [BE], App did not work

BE: Belgium, DE: Germany, ES: Spain,

5 Challenges and perspectives

The tested technologies for pest and disease monitoring of vegetable crops are useful practical tools but are still in their developing stages. To be more applicable in crop management they need to include more crops,pests and diseases that are currently not included. After the test of technologies carried out in the last season of 2022, we highlight the following challenges and perspectives for future use and development of these technologies.

Table 29 – Challenges and perspectives of tested smart technologies for pest and diseases monitoring

Technology group and sub-group	Challenges	Perspectives
Monitoring **Insect**	**Trapview:** • Algorithms only working for specific pest. **Captrap:** • Available only in French version, that makes not easy to use. **iScout:** • Available for the moment for couple of vegetable crops	**Trapview:** • Has strong potential, but identification spectrum on further vegetable crops should be expanded. **Captrap:** • Has been tested and it is a good tool, nevertheless, the version in other languages besides French should be done. It will facilitate the use in other countries. **iScout:** • Has a potential and should be included further vegetable crops and algorithms should be trained for an accurate monitoring.
Diagnosis and detection **Disorder detection mobile Apps**	**Plantix App:** • In its list of crops are not many vegetable crops included, similar with the pest and diseases, e.g., this was the case of *Phyllotreta spp.* In cabbage, which is not included. **Cropalyser App:** • It is practical App and with good quality of pictures, however it needs a previous training for an appropriate use during monitoring.	**Plantix App:** • It is a helpful tool and support on the identification and monitoring of pest and diseases, however, is not available for German version. **Cropalyser App:** • The list of diseases and pest are in a list, nevertheless further vegetables crops should be included. It should be considered to use this App without an internet connexion, it can be very helpful.
Decision support **(no sensors)**	**Xarvio Scouting App:** • This is a practical tool, that besides offer other tasks to do on the plants. Nevertheless, the limitation is that after submitting a picture, the results offer one picture, and this is not helpful for comparing. Besides, that as outcome and recommendations, the Application provides a link, which the user can visit the website for purchasing products (not company-independent). **Agrio App:** • This app is quite similar to Plantix App, with the questionnaire, it helps to fix what the user wants after submitting the picture. For the moment, commercial and known vegetable crops are available in the list. **Bioline App:** • This application works like a field book and manual application similar to Cropalyser App, but, as a data bank for control of pest with biological control. Not many crops are available, commercial, and known, e.g., tomato, cucumber. For the moment, is available in English and not for German version.	**Xarvio Scouting App**: • The App should be improved and have the option to have around three pictures with good quality, it would help during comparing over the plant part affected or leaf or fruit. **Agrio App:** • The free version of this Application is good, however, when the user wants to select some menus or options, it suddenly pop-up ads. The help and support for the identification is quite good, but there is only an English version of this Application. **Bioline App:** • This application is not very known, although biological control is promising. This technology should be promoted further.

6 Key findings

Testing eight technologies, in different places, vegetable crops and cropping systems provided some good and interesting outputs:

- The smart trap Trapview succesfully identified *Tuta absoluta* in tomato crop, which was demonstrated in both Portugal and the UK. It also identified *Psila rosae* in carrot in Latvia and the United Kingdom. *Tuta absoluta* is a major constraint in tomato cultivation and so Trapview provides potential as an alternative method for its monitoring in an effective IPM protocol.
- Smart applications, both automatic image recognition and manual databases when combined together appear to be practical in verifying if the identified pest or disease is correct. Still some applications like Plantix or Agrio do not have many vegetable crops, pests and diseases in their image data base.
- Applications that require a manual procedure for pest and disease monitoring have potential, however they require previous training and knowledge of crops and their pests and diseases to be able to navigate and successfully identify the problem.
- Smart traps and mobile application technologies without sensors work well in aiding with pest and disease monitoring when connected to the internet or have access to mobile data. They do not when no internet connection is available.

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