



RESEARCH BEARS ITS FRUITS

**INTERDEPARTMENTAL CENTRE OF THE
UNIVERSITY OF TORINO**

REPORT OF ACTIVITIES

2023

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EXECUTIVE SUMMARY

In 2023 the research activity of the Interdepartmental Centre AGROINNOVA was carried out in the frame of national and international research projects in collaboration with many partners and stakeholders in Italy and abroad.

The research activities concentrated on three main topics:

- Biology, epidemiology, and management of plant pathogens of economically important crops, with special emphasis on soil-, seed-borne, fruits, forestry and wood diseases.
- Molecular diagnostics and seed-borne pathogens detection
- Plant and food biosecurity, food safety and circular agriculture in the frame of circular health.

The research activities carried out by AGROINNOVA researchers resulted in 36 scientific peer reviewed publications on ISI journals. AGROINNOVA established new collaborations and networks with institutional and private partners in Italy and worldwide.

ORGANIZATION

On October 10, 2022, AGROINNOVA was renewed as Interdepartmental Centre for the Innovation in the Agri-environmental sector of the University of Torino. The organization of the renewed centre maintains the President, and it contemplates: the Director, the management committee (Annex I), composed by 12 members representing 10 departments of the University of Torino, and a scientific committee (Annex II), composed by the President, the Director and 11 members representing 10 departments of the University of Torino. On April 12, 2023, Prof. Alberto Alma, elected by the management committee, was nominated by the Rector as Director of the centre for three years.

The team is composed by 22 researchers (Annex III) that participate to manage and carry out research projects and dissemination activities.

RESEARCH ACTIVITY

a. Biology, epidemiology, and management of pathogens of economically important crops

AGROINNOVA operates in the frame of European and national projects to ensure food security systems, it offers services to protect biodiversity while developing practical solutions to predict, to prevent and to protect agriculture and forestry systems from native and alien pests' threats. The activity deals with identification of emerging pathogens, development of practical solutions for surveillance and monitoring, development of practical solutions for protection, management, and eradication. The effectiveness of these solutions is assessed, validated, and transferred through innovative research and demonstrations.

In 2023, disease monitoring activities were carried out in nurseries, in private gardens as well as in forests located in Piedmont and Liguria (Northern western Italy) with the collaboration of farmers, technicians, and private citizens. The new causal agents of the diseases were identified by observing their morphological characteristics *in vivo* and/or *in vitro* on pure cultures of the isolates obtained from affected plants. Molecular analyses confirmed the morphological identification. The pathogenicity of new microorganisms was always tested reproducing symptoms on healthy plants.

Ornamentals

On *Digitalis purpurea* (Scrophulariaceae), punctiform leaf spots were observed on the old basal leaves. These alterations spread causing the death of the affected leaves and, occasionally, of the entire affected plants. The morphological characteristics of the pathogen isolated *in vitro* were consistent with the genus *Pythium* sp. and the sequencing of the gene COI (GenBank Accession No. MZ717162) showed 99.82% similarity with the ex-type CBS11880 of *P. aphanidermatum* (HQ708485).

On plants of *Hydrangea paniculata* (Hydrangeaceae) irregular necrotic brown spots, 1 to 5 mm in size, randomly diffused on the leaf surfaces were observed. The most affected tissues yellowed and dropped. Dark green fungal colonies were isolated from affected leaves with morphological characteristics similar to the genus *Alternaria*. Molecular analyses performed with the RPB2, the *tef1* and the *endoPG* primers identified the pathogen as *A. alternata*.

Plants of *Anemone japonica*, Japanese anemone (Ranunculaceae), showed leaf chlorosis and wilting, followed by the collapse of affected plants that finally dried out. Roots showed brown discoloration and they were characterized by the presence of a soft rot. Colonies of an Oomycete-like organism

was isolated. Molecular analysis was performed using primers for the cytochrome oxidase 1 (COX1) gene region and they identified the isolate as *Globisporangium sylvaticum*.

Seedlings of *Verbascum chaixii* "Album" (Scrophulariaceae) showed light brown necrotic spots that expanded irregularly to the entire leaf surface that finally rotted. Diseased plants died. Fungal colonies isolated from affected leaves were olive green, showed alternating and concentric rings and produced spheroidal brown. The ITS (Internal Transcribed Spacer) analysis identified the pathogen as *Heterophoma verbasci-densiflori*.

Symptoms of rotting and browning were observed on the base of stems of *Plectranthus scutellarioides*, (Lamiaceae). Leaves and affected petioles wilted and fell off. In some cases, the plant broke at the base and collapsed. A soft, grey mycelium appeared on affected tissues. Colonies typical of *Botrytis cinerea* grown in vitro. The G3PDH, NEP1 and NEP2 regions were examined with molecular analyses and confirmed the identification of *B. cinerea*.

During spring 2023 symptoms of stunting, wilting, and withering of the basal leaves were observed in several fields of *Artemisia pontica*, *Artemisia absinthium* and *Satureja hortensis* located in Piedmont, Northern Italy. A total of 188 fungal colonies morphologically similar to *Fusarium* spp., *Phoma* spp., *Diaporthe* spp., and *Rhizoctonia* spp. were isolated from symptomatic crowns and roots of *A. pontica* and *A. absinthium*, while nine colonies of *Verticillium* spp. were isolated from necrotic stem tissues of *S. hortensis*. A preliminary molecular identification, based on the ITS region (primer set: ITS1/ITS4), was carried out on 48 representative isolates and the identity of the strains was confirmed by sequencing. Pathogenicity tests will be performed inoculating representative isolates selected from each fungal genus. Seedborne pathogens and the phytosanitary conditions of *S. hortensis* were evaluated testing 400 seeds per sample of two different farms located in Piedmont. Seeds were plated on potato dextrose agar (PDA) and incubated for 7 days at 25 °C. Several fungal and bacteria colonies were isolated and stored. Germinability was tested sowing 200 seeds per sample in sterilized sand, showing no symptoms.

Project: AGROINNOVA DIAGNOSTICS Laboratory; research contract with Cooperativa Erbe Aromatiche Pancalieri (CEAP).

Publications on ISI Journals (see also Annex V)

- Bertetti D., Rettori A., Martinis R., Guarnaccia V., Tabone G., Garibaldi A., Gullino M. L. (2023) - First Report of *Neofusicoccum parvum* causing stem cankers and woody rot on *Eucalyptus globulus* in France. *Plant Disease*, 107, 2548.

- Garibaldi A., Bertetti D., Martino I., Luongo I., Gullino M. L. (2023) - First Report of *Heterophoma verbasci-densiflori* on *Verbascum chaixii* "Album" in Italy. Journal of Plant Pathology, in press.
- Garibaldi A., Bertetti D., Martino I., Gullino M. L. (2023) - First Report of Botrytis Blight Caused by *Botrytis cinerea* on *Plectranthus scutellarioides* in Italy. Plant Disease, in press.
- Garibaldi A., Bertetti D., Tabone G., Luongo I., Gullino M. L. (2023) - First Report of Leaf Spots Caused by *Alternaria alternata* on *Hydrangea paniculata* in Italy. Journal of Plant Pathology, Journal of Plant Pathology, 105, 599.
- Garibaldi A., Bertetti D., Tabone G., Luongo I., Gullino M. L. (2023) - First Report of Root Rot Caused by *Globisporangium sylvaticum* on *Anemone japonica* in Italy. Plant Disease, Plant Disease, 107, 2267.

Other publications

- Bertetti D., Rettori A., Martinis R., Guarnaccia V., Tabone G., Gullino M. L., Garibaldi A. (2023) - Presenza di *Neofusicoccum parvum* su due piante ornamentali in Francia: *Schinus molle* ed *Eucalyptus globulus*. Protezione delle colture, 16 (3), 15-18.
- Bertetti D., Martino I., Gullino M. L., Garibaldi A. (2023) - Presenza di *Botrytis cinerea* su piante di *Plectranthus scutellarioides* in Italia. Protezione delle colture, 16 (3), 19-20.
- Bertetti D., Tabone G., Gullino M. L., Garibaldi A. (2023) - Presenza di una ruggine causata da *Coleosporium campanulae* su *Campanula trachelium* in Italia. Protezione delle Colture, in stampa.
- Bertetti D., Tabone G., Luongo I., Gullino M. L., Garibaldi A (2023) - Attacchi di *Alternaria alternata* su *Melissa officinalis* in Italia. Protezione delle colture, in stampa.
- Bertetti D., Tabone G., Gullino M. L., Garibaldi A. (2023) - Nuovi parassiti di specie ornamentali segnalati in Piemonte: *Alternaria alternata* su *Melissa officinalis* e *Hydrangea paniculata*; *Globisporangium sylvaticum* su *Anemone japonica*. Atti Incontri Fitoiatrici 2023. Protezione delle colture, 16 (2), 10-11.
- Bertetti D., Rettori A., Martinis R., Tabone G., Gullino M. L., Garibaldi A. (2023) - Nuovi ospiti di *Neofusicoccum parvum* segnalati in Francia: *Schinus molle* ed *Eucalyptus globulus*. Atti Incontri Fitoiatrici 2023. Protezione delle colture, 16 (2), 12-13.

Biology of seedborne pathogens

Several activities started to evaluate propagating material of basil (*Ocimum basilicum*) to identify contamination by *Peronospora belbahrii*, causal agent of basil downy mildew; to monitor the spread

and severity of *P.belbahrii* attacks in basil production areas for pesto production (Emilia Romagna, Veneto and Piedmont) in relation to the cultivation system; to characterize populations of *P.belbahrii* obtained from infected seeds and in the field by assays on selected basil cultivars of known susceptibility.

Out of 15 seed lots tested, 6 were found to be infected with *P. belbahrii*. The field monitoring conducted between June 24 and October 10 in three geographical areas under study resulted in the collection of 37 populations of the pathogens. Nine populations (three from each area) were selected and used in assays carried out under controlled conditions using cultivars of known susceptibility. The results showed that the *P. belbahrii* populations in the Emilia-Romagna area differed from those in Veneto. The Piedmontese populations showed an intermediate virulence. The tests conducted showed 'Prospera', Gervaso, Eleonora, Lemon, Robur, Italiano Classico and Zeus basil cultivars as good differential of *P. belbahrii* populations.

Project: Characterisation of *Peronospora belbahrii* populations obtained from seed and field using differential basil cultivars. 2023-2024

Collaboration: Barilla company

Pome and stone fruits

Severe dieback symptoms were observed on apple (*Malus × domestica*) trees in Northern Italy, representing a growing concern for producers. Thirty-three fungal isolates isolated from symptomatic plants in 5 different orchards surveyed during 2019 to 2021 were selected for characterization. The species identification was achieved through multilocus phylogenetic analyses performed on sequences of three genomic loci (ITS, tub2, and tef1). Morphological features were assessed, and the average growth rate at different temperatures was determined. Seven species were identified in association with dieback of apple trees: *Botryosphaeria dothidea*, *Cadophora luteo-olivacea*, *Diaporthe rudis*, *Diplodia seriata*, *Eutypa lata*, *Kalmusia longispora*, and *Paraconiothyrium brasiliense*. All the species were pathogenic when inoculated on healthy apple plants. *B. dothidea* produced the most aggressive infections. This study provides an insight into the fungal species diversity associated with apple dieback and provides basis for further investigations to assess the phytosanitary status of plant materials to recommend and implement effective management strategies.

White haze, caused by an extensive fungal colonization of the apple surface, is an emerging postharvest issue in several European apple production areas. It results in compromised quality and decreased marketability of the fruits, leading to economic losses. The occurrence and the diversity

of fungi associated with white haze on apples was investigated in Northern Italy. Six species belonging to different basidiomycetous genera (*Entyloma*, *Golubevia*, *Tilletiopsis*) were identified, showing high diversity of fungi involved in white haze development in Northern Italy. The strains were identified as *E. belangeri*, *E. randwijkense*, *G. pallescens*, *T. washingtonensis*. Moreover, two new species, *E. mali* sp. nov. and *G. mali* sp. nov. were described. The most frequently isolated strains were inoculated on healthy apple fruit, showing to be able to reproduce symptoms on red-skin apples, fulfilling Koch's postulates. This work provides new insights to increase knowledge about the causal agents of white haze on apple.

Ramularia mali has been identified as the causal agent of dry lenticel rot. We measured fruit disease incidence and quality parameters, and we used metabarcoding to characterize both epiphytic and endophytic microbial communities of apple fruit of two commercial cultivars, 'Opal' and 'Ambrosia', across six time points from early fruit development up to the end of shelf-life. *R. mali* first develops in both cultivars as an endophyte at BBCH phenological phase 73 (10-11% relative abundance), BBCH 77 (26-33% relative abundance) and BBCH 81 (1-7% relative abundance), then it appears as an epiphyte from BBCH 87 onward (1-2% relative abundance), when symptoms start to be visible. This was confirmed in endophytic samples through qPCR specific for *R. mali*.

Brown and black spots, caused by *Stemphylium* and *Alternaria* species, are important fungal diseases affecting European pear (*Pyrus communis* L.) in orchards. Both fungal genera cause similar symptoms, which could favour misidentification, but *Alternaria* spp. are increasingly reported due to the changing climatic conditions. In this study, *Alternaria* spp. were isolated from symptomatic leaves and fruits of European pear, and their pathogenicity was evaluated on pear fruits 'Abate Fétel' and molecular and chemical characterization were performed. Based on Maximum likelihood phylogenetic analysis on 4 concatenated genes, 15 out of 46 strains were identified as *A. arborescens* species complex (AASC), 27 as *A. alternata* and four were named *Alternaria* sp. Both species were isolated from mature fruits and leaves. All the strains, when inoculated on pear fruits cv. Abate Fétel, reproduced the symptoms, both by wound inoculation and direct penetration. All the strains except for one were able to produce *Alternaria*-toxins on European pears: tenuazonic acid and alternariol (89.1% of the strains), alternariol monomethyl ether (89.1%), altertoxin I (80.4%), altenuene (50.0%) and tentoxin (2.2%). Forty-five out of 46 strains were able to produce at least two mycotoxins and 43.5% produced four mycotoxins, with an average total concentration of the *Alternaria*-toxins exceeding 7.58×10^6 ng/kg. Our data underline the potential risks for human

health related to the high mycotoxin content found on fruits affected by black spot. The study represents the first report of AASC as agents of black spot on European pear in Italy.

Black rot is limiting the production of sweet cherries in Italy. Dark brown to black patches and sunken lesions on fruits are the most common symptoms of *Alternaria* black rot on sweet cherry fruits. We isolated 180 *Alternaria* spp. from symptomatic cherry fruits 'Kordia', 'Ferrovia', and 'Regina' harvested in Northern Italy, over three years, from 2020 to 2022. The aim was to identify and characterize a selection of forty isolates of *Alternaria* spp. based on morphology, pathogenicity, and combined analysis of *rpb2*, *Alt-a1*, *endoPG* and *OPA10-2*. Based on the concatenated sequence of four gene regions, thirty-three out of forty isolates were identified as *A. arborescens* species complex (AASC), and seven as *A. alternata*. Pathogenicity was evaluated on healthy 'Regina' sweet cherry fruits. All the tested strains were pathogenic on their host. This study represents the first characterization of *Alternaria* spp. associated with black rot of cherries in Italy and, to the best of our knowledge, it is also the first report of AASC as an agent of black rot of sweet cherries in Italy.

Projects: "Diagnostica innovativa delle malattie delle piante con particolare riferimento alla diagnostica a distanza e di campo" financed by the Fondazione Cassa di Risparmio di Saluzzo.

"POSTFRUIT: Difesa post- raccolta dei prodotti ortofrutticoli" financed by Fondazioni Bancarie Cuneesi.

Publications on ISI journals (see also Annex V):

- Martino, I., Agustí-Brisach, C., Nari, L., Gullino, M. L., & Guarnaccia, V. (2023). Characterization and pathogenicity of fungal species associated with dieback of apple trees in Northern Italy. *Plant Disease*, (in press).
- Guarnaccia, V., Remolif, G. M., Nari, L., Gualandri, V., Angeli, D., Oetl, S., ... & Spadaro, D. (2024). Characterization of fungal species involved in white haze disorder on apples in Northern Italy and description of *Golubevia mali* sp. nov. and *Entyloma mali* sp. nov. *Postharvest Biology and Technology*, 209, 112678.
- Prencipe S., Meloni G.R., Nari L., Schiavon G., Spadaro D. (2023) - Pathogenicity, molecular characterization and mycotoxigenic potential of *Alternaria* spp. agents of black spots on fruit and leaves of *Pyrus communis* in Italy. *Phytopathology*, 113 (2), 309-320. DOI: 10.1094/PHYTO-03-22-0103-R
- Waqas M., Prencipe S., Guarnaccia V., Spadaro D. (2023) Molecular Characterization and Pathogenicity of *Alternaria* spp. associated with Black Rot of Sweet Cherries in Italy. *Journal of Fungi*, 9, 992. DOI: 10.3390/jof9100992

Kiwifruit

Since 2012, the kiwifruit vine decline syndrome (KVDS) has progressively compromised Italian kiwifruit orchards. Different abiotic and biotic factors have been associated with the establishment and development of KVDS. During monitoring of orchards affected by KVDS in north-western Italy during 2016-2019, 71 *Phytophthium* spp. were isolated. In 2023 based on maximum likelihood concatenated phylogeny on the ITS1-5.8S-ITS2 region of the rDNA, large subunit rDNA, and cytochrome oxidase I, isolates were identified as *P. vexans* (52), *P. litorale* (10), *P. chamaeophyon* (7) and *P. helicoides* (2). *P. litorale* and *P. helicoides* are reported for the first time as agents of KVDS in Italy. To demonstrate pathogenicity and fulfil Koch's postulates, representative isolates of *P. vexans*, *P. litorale*, *P. chamaeophyon* and *P. helicoides* were inoculated in potted plants. In these trials, waterlogging was applied to stress plants with a temporary anoxia and to favour the production of infective zoospores by the oomycetes. In experiments in vitro, the four species showed the highest growth at 25-30 °C, depending on the media used. *P. helicoides* was able to grow also at 40 °C. The four species were able to grow in vitro at pH ranging from 5.0 to 8.0, showing that pH had less effect on growth than temperature. The present study suggests a strong role of different species of *Phytophthium* in the establishment and development of KVDS. *Phytophthium* spp. could be favoured by the average increase of soil temperatures during summer, associated with global warming.

The work continued with the aim of defining the microbial communities characterizing soil, rhizosphere, and root population present both in affected and healthy fields in North-West Italy, by analyzing the whole pathobiome, as bacteria, fungi, and oomycetes, through metabarcoding. Bacteria and fungi showed a wide diversity, even when grouped by sampling location. Focusing on oomycetes, *Phytophthium* spp. was the main genus across all infected matrices. *Phytophthium* spp. was present in significantly higher abundances in diseased orchards, compared to healthy ones, showing a statistically significant correlation with the occurrence of the syndrome. From the same sites, isolation was performed through the years revealing the presence of *Phytophthium* spp. mainly associated to symptomatic roots. Bacteria, fungi, and oomycetes were considered together for the first time, reinforcing the role of *Phytophthium* spp. in KVDS.

Projects: "From SOil to Soil: origin and remediation to KIWIfruit Vine Decline Syndrome (SOS-KIWI)", funded by AGER - Fondazioni in Rete per la Ricerca Agroalimentare; research contract "EFFICACIA DI PREBIOTICI E PROBIOTICI PER CONTRASTARE LA MORIA DEL KIWI" with Biolchim.

Publications on ISI journal:

- Prencipe S., Schiavon G., Rosati M., Nari L., Schena L., Spadaro D. (2023) Different species of *Phytophthium* are involved in the establishment and development of Kiwifruit Vine Decline Syndrome. *Microorganisms*, 11, 216. DOI: 10.3390/microorganisms11010216

Other publications

- Nari L., Berra L., Bardi L., Monaco S., Mandala C., Morone C., Spadaro D., Guaschino M., Giorgi V., Neri D. (2023) Misure agronomiche unica strada possibile per prevenire la moria. *Rivista di Frutticoltura*, 85 (7), 32-38
- Nari L., Berra L., Bardi L., Monaco S., Mandala C., Morone C., Spadaro D., Guaschino M., Giorgi V., Neri D. (2023) Moria, misure agronomiche unico strada percorribile. *Terra e Vita* 64 (31), 40-43.

Cereals

The genus *Fusarium* includes several agronomically important and toxin-producing species that are distributed worldwide and can cause a wide range of diseases. Crown and stalk rot and grain infections are among the most severe symptoms that *Fusarium* spp. can cause in maize. In 2023 a study initiated in 2021 to assess and identify the *Fusarium* species complexes causing stalk and root rot of maize in Northern Italy was concluded. Representative isolates were identified as species belonging to three species complexes (SC), including *Fusarium verticillioides* and *F. annulatum* in the *F. fujikuroi* SC. *Fusarium commune* was identified in the *F. nisikadoi* SC, and three different lineages were found in the *Fusarium oxysporum* SC. This study reports *F. annulatum* and two lineages of the *Fusarium oxysporum* SC as maize pathogens for the first time in Italy.

Pyricularia oryzae (syn. *Magnaporthe oryzae*) was reported for the first time on common millet (*Panicum miliaceum* L.), a niche crop cultivated in Italy for its high nutritional and gluten-free characteristics. These aspects, combined with its sustainability and adaptability to paddy soils, make it relevant in crop rotation with rice in some organic farms in Northwestern Italy.

Project: AGROINNOVA DIAGNOSTICS Laboratory.

Collaborations: Consorzio Agricolo Piemontese Per Agroforniture E Cereali Soc Coop Agricola (C.a.p.a.c. S.r.l.), Cso. Francia 329, Torino; Azienda Agricola Una Garlanda di Stocchi fratelli e C., Rovasenda (VC).

Publications on ISI journals (see also Annex V):

- Sanna, M., Luongo I., Gullino M.L., Mezzalama M. First Report of Gray Leaf Spot Caused by *Pyricularia oryzae* on Common Millet in Italy. 2023. *Plant Disease*, 107, 4, 1231.

- Sanna, M.; Martino, I.; Guarnaccia, V.; Mezzalama, M. Diversity and Pathogenicity of *Fusarium* Species Associated with Stalk and Crown Rot in Maize in Northern Italy. 2023. *Plants* 12, 3857. <https://doi.org/10.3390/plants12223857>.

Grapevine

Morphological and multi-locus phylogenetic analyses (based on ITS, *tef1*, *tub2*, *act* and *rpb2*) was carried out on trunk disease pathogens isolated in Piedmont in 2022. Species of Botryosphaeriaceae were identified at high frequency, including *Botryosphaeria dothidea*, *Diplodia mutila*, *D. seriata* and *Neofusicoccum parvum*. Other pathogens commonly associated with trunk diseases, including *Eutypa lata*, *Fomitiporia mediterranea* and *Phaeomoniella chlamydospora*, were also isolated. Less commonly isolated species included *Neocucurbitaria juglandicola*, *Paraconiothyrium brasiliense*, *Seimatosporium vitis-viniferae* and *Truncatella angustata* were detected. Pathogenicity tests with two representative isolates of each species were carried out using one-year-old potted grapevine cuttings ('Barbera'). All isolates (except *N. juglandicola*) caused brown wood necrotic vascular discolorations on inoculated plants and were successfully re-isolated. Effects of temperature on colony growth were also assessed. For all tested isolates there was no growth at 5°C, only four isolates (Botryosphaeriaceae) grew at 35°C, and optimum growth temperatures were between 20 and 25°C. This is the first record of *Paraconiothyrium brasiliense* and *Neocucurbitaria juglandicola* associated with symptomatic grapevines in Italy.

Project: "Diagnostica innovativa delle malattie delle piante con particolare riferimento alla diagnostica a distanza e di campo" funded by the Fondazione Cassa di Risparmio di Saluzzo.

Publications on ISI journal

- Dardani, G., Mugnai, L., Bussotti, S., Gullino, M. L., & Guarnaccia, V. (2023). Grapevine dieback caused by *Botryosphaeriaceae* species, *Paraconiothyrium brasiliense*, *Seimatosporium vitis-viniferae* and *Truncatella angustata* in Piedmont: characterization and pathogenicity. *Phytopathologia Mediterranea*, 60, 283-306.

Citrus

Anthraxnose, post bloom fruit drop, fruit stem-end rot, twig and branch dieback and gummosis, caused by *Colletotrichum* spp. are diseases that seriously threaten citrus production. Surveys of kumquat (*Fortunella margarita*) orchards were conducted in Eastern Sicily, Southern Italy, during 2022-23. Fungi isolated from twig and branch dieback of *F. margarita* were identified as *Colletotrichum karsti* through multi-locus (*gapdh*, *tub2* and *act*) phylogeny. Pathogenicity and aggressiveness on detached apple fruit and kumquat plants were confirmed for a selection of

representative isolates, although with different levels of disease incidence observed. This is the most comprehensive study on identification of *C. karsti* as the causal agent of twig and branch dieback of kumquat.

In the frame of the project Keyplex the Phylogenetic analyses of the isolates obtained from the survey carried out in Florida during 2022 allowed the identification of three different species: one Botryosphaeriaceae species, *Lasiodiplodia iraniensis*, and two *Diaporthe* species, *D. pseudomangiferae* and *D. ueckerae*. The pathogenicity of the identified species was confirmed with trials both on citrus fruits and trees.

Project: Research Agreement Agroinnova-Keyplex: Etiology and control of Colletotrichum diseases on citrus in Florida

Publications on ISI journal (see also Annex V):

- Leonardi, G.R., Aiello, D., Camilleri, G., Piattino, V., Polizzi, G., & Guarnaccia, V. (2023). A new disease of kumquat (*Fortunella margarita*) caused by *Colletotrichum karsti*: twig and branch dieback. *Phytopathologia Mediterranea*, 333-348.

Forest trees

In cooperation with the Istituto per le Piante da Legno e l'Ambiente (IPLA) and on behalf of Regione Piemonte, in the autumn of 2023 the project aimed at monitoring and modelling Ash dieback caused by *Hymenoscyphus fraxineus* in Piedmont initiated. As in 2022, 17 sites hosting ash (*Fraxinus excelsior*) were surveyed and sampled.

Project: Research Agreement Agroinnova-Istituto per le Piante da Legno e l'Ambiente (IPLA) on behalf of Regione Piemonte, Linee guida operative e strategiche per la conservazione del frassino in Piemonte (LOSFRAP).

b. Prevention and control

Management of *F. oxysporum* f. sp. *lactucae*

In the frame of the project SFIDA, trials were carried out under controlled conditions in soilless and in phytotrons, aiming at developing and evaluating the effectiveness of integrated pest management strategies in the pathosystem lettuce - *F. oxysporum* f. sp. *lactucae* (races 1 and 4).

Experiments were carried out in a closed soilless system to assess the effectiveness of resistance inducers (inorganic salts) and biocontrol agents such as the antagonistic *F. oxysporum*, *Trichoderma* spp., *Bacillus subtilis* and the entomopathogenic agent *Beauveria bassiana* applied alone and in combination within an integrated pest management strategy against race 4 of *F. oxysporum* f. sp. *lactucae* on lettuce, and on microbiological hygiene indicators. The experimental non-pathogenic *F.*

oxysporum MSA35 strain provided a higher significant disease severity reduction (50-73% efficacy) than the commercial *B. subtilis* and *B. bassiana* formulations. Also, the commercial formulation of *B. subtilis* only slightly reduced the severity of wilt symptoms caused by race 4 (26 to 32% efficacy) of the pathogen. Such data seem in contrast with the results previously obtained, against race 1. In the present study, potassium phosphite, calcium oxide and K-phosphite applied alone did not contain the disease efficiently, but when the different products were tested in integrated programs alternating the micro-organism MSA35 with CaO or with K-phosphite, the health of the culture was significantly improved. The leaf tissue samples analysed from lettuce grown in experimental soilless and subjected to innovative treatments, showed a reduction in total microbial hygiene indicators and enterobacter levels, compared to an untreated control, thus meeting process hygiene criteria. Preliminary results from the management of lettuce grown soilless with resistance inducers and antagonistic microorganisms did not reveal any critical issues from the point of view of product health and their suitability under commercial conditions. A study under phytotron conditions, provided understanding about how the tested biocontrol agents and resistance inducers respond to climate change. Combined impact of elevated temperature (20-24°C, 24-28°C, 28-32°C) and CO₂ levels (800–850 ppm) compared to standard CO₂ concentrations on calcium oxide, potassium phosphite, *Streptomyces griseoviridis*, *Trichoderma asperellum* and *Beauveria bassiana* in the lettuce-*Fusarium oxysporum* f. sp. *lactucae* (race 1) pathosystem was evaluated. Temperature was the main factor that influenced *Fusarium* wilt severity in the inoculated and untreated controls and the efficacy provided by the tested products. Potassium phosphite generally provided consistent disease reduction under all the tested conditions, and it resulted to be more effective at 20-24°C × 400-450 ppm of CO₂ (76% efficacy) than at 800 ppm of CO₂ (47% efficacy), while calcium oxide provided the greatest lettuce wilt severity reduction (43% - 46% efficacy) at 20-24°C, with the tested CO₂ concentrations having no significant effect. *B. bassiana* provided consistent disease control at 20-24°C (53-56% efficacy) for both CO₂ concentrations, while increases in CO₂ significantly improved the efficacy of *S. griseoviridis* across this temperature range. *T. asperellum* was inconsistent in the biocontrol of the pathogen under all the tested environmental conditions. Potassium phosphite and *B. bassiana* provided the best *Fusarium* wilt reduction, that is, of 23-35% and 28-32%, respectively, for the 24-28°C temperature range and for both the tested CO₂ concentrations, while calcium oxide was only effective for the standard CO₂ level (30% efficacy). None of the tested biocontrol agents were effective at 28-32°C with 400-450 ppm of CO₂.

Collaborations:

Project: SFIDA – Low environmental impact management strategies for the horticultural sector, 2019-2024

Publication on ISI journal

- Gilardi G., Tabone G., Gullino M.L., Garibaldi A. (2023) Effect of the use of biocontrol agents and resistance inducers against race 1 of *Fusarium oxysporum* f. sp. *lactucae* on lettuce in a simulated climate change scenario. *Journal of Plant Pathology*, 106, 23-30.

Management of citrus diseases

Almost two hundred strains were isolated from symptomatic fruit and twigs samples and identified by morphological and molecular characterization. *Colletotrichum* spp. were the most frequently isolated species followed by Botryosphaeriaceae and *Diaporthe* spp. *In vitro* tests were performed to assess the sensitivity of *Colletotrichum* spp. to fungicides belonging to different chemical groups largely used to control fungal diseases in Florida. Testing was conducted through eight concentrations. The sensitivity was estimated through the percentage inhibition of conidia germination. In addition, two essential oil based products were tested *in vitro* and on citrus fruit to assess their efficacy against *Colletotrichum* diseases. This experiment is ongoing. Moreover, a peptide based product was tested on *Citrus sinensis* plants to evaluate its effectiveness to reduce biotic stress on plants artificially inoculated with *Diaporthe* and Botryosphaeriaceae species. This experiment is also ongoing.

Project: Research Agreement Agroinnova-Keyplex: Aetiology and control of *Colletotrichum* diseases on citrus in Florida

Management of cereal diseases

Tolerance to rice blast of three rice cultivars, supplied by CREA Vercelli, was tested in 2023 to confirm the reliability of the protocol tested in previous years. A blast resistant (Arsenal), a susceptible control (Vialone Nano) and a newly bred CREA cultivar were challenged with *P. oryzae* strains IT02, IT03 and IT10, Italian reference strains characterized by Roumen et al. (1997). Cultivars Arsenal and Vialone Nano presented the expected tolerance degree, with an average disease severity between both trials and with all *P. oryzae* strains tested of, respectively, 4.33 and 40.36%. The new cultivar presented an average disease severity of 4.56%, which was not statistically different from non-inoculated controls of all cultivars according to Tukey's test, thus it showed a degree of tolerance to rice blast like Arsenal. Finally, among *P. oryzae* strains virulence, no statistical differences were found.

Bakanae disease has become a concern for seed companies and farmers as fludioxonil, the only conventional active ingredient allowed for *F. fujikuroi* control, is a candidate for substitution in the EU. The main disadvantage of biocontrol agents is their reduced efficacy in field conditions. Endophytes, on the other hand, due to their close relationship with the host, are theoretically less susceptible to abiotic stressors. The aim of the work was to select potential biocontrol agents for preventive seed dressing against *F. fujikuroi* among a collection of rice endophytes isolated from 24 Italian cultivars. In planta screenings were performed using a total amount of 135 isolates to select endophytes capable of reducing bakanae symptoms similarly to fludioxonil under controlled conditions. The selected strains were molecularly identified and tested for their potential to inhibit *F. fujikuroi* in vitro. A second in vivo biocontrol efficacy assay allowed to confirm the selection of 6 endophytes, 4 bacterial and 2 fungal strains, due to their ability to reduce bakanae disease severity up to 50%.

Projects: AGROINNOVA DIAGNOSTICS Laboratory, research contract “Valutazione della suscettibilità varietale nei confronti di *Pyricularia oryzae* su riso” with CREA, research contract “Approccio integrato alla difesa da fusariosi e brusone del riso”.

Collaborations: CREA - Consiglio Per La Ricerca In Agricoltura e L'Analisi dell'Economia Agraria - Cerealicoltura e Colture Industriali, Vercelli; SA.PI.SE. Coop. Agricola, Vercelli.

Publication on ISI journal:

- Bosco S., Guarnaccia V., Mezzalama M., Spadaro D. (2023) Selection of endophytes isolated from Italian rice cultivars as biocontrol agents against *Fusarium fujikuroi*. Journal of Plant Pathology, 105, 100.

Management of turfgrass diseases

Evaluation of the effectiveness of biostimulants, is carried out in combinations with microorganisms that could be antagonists of the most common turfgrass diseases in Italy, in particular *Claviceps* spp. (Dollar spot) and *Rhizoctonia solani* (brown patch) and recently to the introduced warm season grasses disease (*Bipolaris* spp.) and, in addition, evaluate the effects of these products on stress resistance. Preliminary results showed a low efficacy of tested products. Trials will be repeated to identify solutions to be tested next year in field conditions.

Project: The Royal and Ancient Championship - Effects of biostimulants and microorganisms against most common turfgrass diseases in Italy, 2022-2024

Genetic resistance

Selection of horticultural varieties of different species under greenhouse conditions and artificial inoculations were carried out to evaluate genotypes for resistance to critical pathogens:

on Zucchini (*Cucurbita pepo*): *Podosphaera xanthii*, *Pseudoperonospora cubensis*, *Fusarium solani* f.sp.*cucumerinum*, *Phytophthora capsici*.

On lettuce (*Lactuca sativa*): race 1 of *Fusarium oxysporum* f.sp.*lactucae*.

On lamb's lettuce (*Valerianella olitoria*): *Fusarium oxysporum* f.sp.*raphani*.

On wild rocket (*Diplotaxis tenuifolia*): *Fusarium oxysporum* f.sp.*raphani*.

On basil (*Ocimum basilicum*): *Peronospora belbahrii*.

Selection of rice varieties under greenhouse conditions and artificial inoculations were carried out to evaluate genotypes for resistance to *Fusarium fujikuroi* and *Pyricularia oryzae*.

Collaborations: service provided to:

Blumen, Gautier, Maraldi, Sativa and SA.PI.SE seed companies;

Research and Certification institute CREA-DC .

Monitoring and predicting

In 2023 in the frame of the project MONITORA field monitoring was carried out to map the distribution of foliar and soilborne pathogens of onion, potato, and tomato in commercial fields and to implement a Decision Support System specific for these pathosystems. Target pathogens were *Phytophthora infestans* and *Alternaria* spp. for tomato and potato crops, *Peronospora destructor*, and *Stemphylium* spp. for onion crop. The monitoring activity was useful for the acquisition of field and meteorological data to prepare empirical alert systems, based on the findings/alerts of the users of the platform. During the season, several symptomatic samples were collected and analyzed, and the outcome of the surveys was recorded in Excel documents shared with the project partners to improve the alert system. Most of the target pathogens were observed, like *Alternaria* spp. on tomato and potato, and *Stemphylium* spp., and *P. destructor* on onion. Other fungal strains were isolated from symptomatic plants, like *Fusarium* spp. and *Botrytis* spp. from onion plants and bulbs, and bacteria and *Fusarium* spp. from potato plants and tubers. In order to establish the parameters necessary for the development of empirical forecasting models and warning systems for target patho-systems (*Stemphylium vesicarium* - onion, *Alternaria solani* - potato, *Alternaria solani* - tomato, *Phytophthora infestans* - potato, *Phytophthora infestans* - tomato and *Peronospora destructor* - onion) the optimal conditions of temperature, relative humidity, leaf wetness and precipitation for the development of target pathogens were compared with the real meteorological

conditions that occurred in the fields. The models were developed based on the climatic parameters identified during the 2022 campaign, and their performances were compared with known models, like the IPI model, developed by the Emilia Romagna Region for *P. infestans*, or the Tomcast model for *Alternaria* spp. The alerts generated by the platform were compared with data recorded during the monitoring activity. Field inspections were carried out to validate the DSS after the alerts were generated by the system to verify the effective development of the symptoms caused by target pathogens. The inspections confirmed the use of correct meteorological and phenological parameters for the generation of sensitive alert, allowing the early detection of pathogens on sentinel crops and the consequent phytosanitary treatments to contain the disease in the field. Treatments were performed in different ways, following two different protocols, one defined by the farmer and one defined by the project and based on the alerts generated by the system. During the field inspections, symptomatic samples of tomato, onion and potato were collected to identify soilborne pathogens that affect the crops and are responsible of yield and production losses. The diagnosis was based on traditional and molecular methods to identify the species involved in the symptoms observed in the field. During 2023, strains of *Fusarium oxysporum* f. sp. *cepae* and *F. proliferatum* and *Fusarium* spp. were isolated from onion plants, potato plants and tubers. Data were recorded in the platform of the project MONITORA. Phytosanitary condition of propagation material was evaluated for onion and potato crops. Onion seeds of 3 cultivars (Elenka, Honeymoon and Solstice) showed high percentages of *Fusarium* spp. (10.8%) in cultivar Elenka and *Alternaria* spp./ *Stemphylium* spp. (11.3%) in cultivar Solstice. Potato tubers were analysed and high percentages of *Colletotrichum coccodes* (42%) and *Fusarium* spp. (40%) were isolated. Four open days were carried out in the farms involved in the project. During the events, the experimental setup of the tests performed was presented to the participants. The tests were characterized by a comparison between irrigation and treatments management that followed the farmer's approach and the "MONITORA" management protocol, with the aim of rationalizing production inputs to improve economic and environmental sustainability.

Project: MONITORA, for the development of alert and decision-making systems for the integrated pest management of industrial crops in the field. Regione Piemonte

Precision agriculture

To identify and introduce an optimal vineyard management model a best practice based on the use of a series of innovative precision viticulture tools are implemented to know better the state of health of the crop in a timely manner and to be able to apply control strategies based on the actual

conditions of the vineyard. Within the VI.P project, a vineyard located in Castiglione Tinella (Cuneo Province) was weekly monitored by visual scouting during spring-summer 2023 for the development of downy and powdery mildew infections. An experimental protocol was applied in the vineyard, comparing the standard farmer disease management practice to an experimental integrated disease management strategy supported using disease prediction models, an organic farming strategy supported by the use of disease prediction models, a precision crop protection strategy supported by an electric precision sprayer developed by project partners. The IPM and organic strategies were able to control the diseases in a similar way than the farmer practice. Together with the project partner IDS, the vineyard was scouted with drones equipped with multispectral cameras to investigate and correlate the plant disease development with the collected images. The elaboration of images collected was able to identify diseased plants and separate the healthy one from the infected ones. Some limitations of this detection system were identified.

Project: Progetto PSR Regione Piemonte – VI.P. Viticoltura di precisione, 2020-2024

Electrification in agriculture

The electrification of agricultural equipment is a challenge involving the world's largest producers in the sector. The transition from traditional mechanical and oleodynamic systems to a fully electric drive can bring important benefits. The Regional project MARCEL aims to develop a fully integrated system regulating the control of electric motors and implements, devices and architectures dedicated to the integration of equipment with associate sensors, the tractor setup, the generation and remote data acquisition/storage systems. Agroinnova's role was to assess the effectiveness of developed agricultural equipment's, under experimental and in field conditions, with a view to reduce plant protection products applied to grapevine and to optimizing disease management. After the development of the prototypes, carried out by project industrial partners Fiat-CNH, Dragone, Spezia, Fissore, AGROINNOVA during 2023 carried out experimental field trials comparing the electrified systems to the traditional ones. No differences were observed between electrified equipment and traditional systems. Furthermore, a specific evaluation was done on the application of UV lights in a vineyard located in Scaparoni (Cuneo Province) to stimulate natural defense mechanisms and consequently reduce the amount of pesticides applied. A reduction of downy and powdery mildews on both leaves and bunches was observed on grape cv Arneis and Favorita by the application of UV lights.

Project: Progetto PIATTAFORMA Regione Piemonte – MARCEL. Macchine Agricole Elettriche. 2021-2023

Publications

Pugliese M., Trucco F., Gullino M. L., Garibaldi A. (2023) – Efficacia di strategie di difesa dalla peronospora della vite che prevedono l'utilizzo di irroratrici smart e di mezzi di lotta a ridotto impatto ambientale. *Protezione delle Colture*, 2, 22-23.

Pugliese M., Trucco F., Gullino M. L., Garibaldi A. (2023) – Applicazione di raggi UV-C in vigneto per il contenimento di peronospora e oidio. *Protezione delle Colture*, 2, 24-25.

c. Molecular diagnostics; diagnostic test validation; detection of seedborne pathogens; detection of fruit and berry fruit leaf, wood, and root pathogens.

Ramularia mali causes dry lenticel rot on apple (*Malus domestica*). A SYBR Green qPCR assay was developed, using *calmodulin* as target gene, for the detection and quantification of *R. mali* in apple fruits. The qPCR assay was validated in terms of specificity, sensitivity, repeatability, and reproducibility following the international EPPO standard PM 7/98. The primers amplified a region of 237 bp specific to *R. mali*. The specificity was validated with 20 fungal species commonly found on apple, 36 strains of *R. mali* and closely related species of the *R. eucalypti* species complex. Positive amplifications were obtained only with DNA of *R. mali* and no cross-reaction was detected with the other fungal species. Sensitivity was assessed with serial dilutions of target DNA and the limit of detection was 100 fg. No influence of host DNA was observed when target DNA was diluted on the DNA of 'Ambrosia' and 'Golden Delicious' apple. The assay permitted to detect and quantify *R. mali* in symptomatic and asymptomatic fruits. The presence of *R. mali* on asymptomatic 'Ambrosia' and 'Golden Delicious' apples was demonstrated, and the presence of the pathogen was reported for the first time on 'Jeromine', 'Gala', 'Opal' and 'Story Inored' fruits. This assay could be useful to clarify the life cycle of this pathogen and build up an effective disease management strategy. Furthermore, the early detection of the pathogen on asymptomatic apples could be used to forecast the development of dry lenticel rot, supporting the packinghouse operators in deciding the duration of storage of apple lots.

A validation of a molecular diagnostic tool targeting the oomycete *Phytophthora vexans* was performed. The best performing primer set was selected and used for validation by means of specificity, sensitivity, selectivity, repeatability, and reproducibility of the qPCR assay according to the international EPPO standards PM 7/98. To evaluate specificity of the assay for *P. vexans* a panel of 20 species comprehending closely related ones, species previously reported on kiwifruit with similar symptoms to KVDS and soil inhabiting species. Calibration curves were performed to

determine the sensitivity with *P. vexans* DNA using the PP1 strain, tenfold serially diluted in sterile water. Repeatability was checked by running independent assays and reproducibility by repeating the assay in different days by different operators. Validation was carried out on a panel of 20 species including strain belonging to *P. helicoides*, *P. chamaehyphon*, *P. litorale*, *Trichoderma* spp., *Fusarium* spp., *Globisporangium* spp., *Ilyonectria* spp. and *Armillaria* spp.. The calibration curve for the sensitivity of the assay resulted in 7 points with the last one corresponding to 10fg of target DNA.

Projects: “Diagnostica innovativa delle malattie delle piante con particolare riferimento alla diagnostica a distanza e di campo” funded by the Fondazione Cassa di Risparmio di Saluzzo.

“From SOil to Soil: origin and remediation to KIWIfruit Vine Decline Syndrome (SOS-KIWI)”, funded by AGER - Fondazioni in Rete per la Ricerca Agroalimentare

Publications on ISI journal (see also Annex V)

- Prencipe S., Valente S., Nari L., Spadaro D. (2023) - A quantitative real-time PCR assay for early detection and quantification of *Ramularia mali*, an emerging pathogen of apple causing dry lenticel rot. *Plant Disease*, 107(5), 1399-1407. DOI: 10.1094/PDIS-07-22-1586-RE

d. Plant and food biosecurity, food safety and circular agriculture in the frame of circular health.

Circular Health

In the frame of the project Circular Health for Industry (CH4I), AGROINNOVA coordinates the activities for the definition of the requirements for the application of the circular-health approach, and of the generic tools and methodologies for data analytics driven process management, with the territorial subproject on Agrifood Industry. During summer 2023 field surveys were organized to evaluate the phytosanitary condition of maize crop, and, in collaboration with DiSAFA, flights were carried with drone technologies for monitoring soil texture, moisture, water stress, crop status and pests and diseases in the field. These data were used with artificial intelligence, mathematical and statistical approaches to model, simulate, visualize and, in general, understand phenomena in agricultural sciences and crop protection. At the same time, in collaboration with Alten and Fudex companies, a traceability system of the entire production chain, from the cultivation of raw materials to the final product, was designed for the agrifood company Fudex based on a blockchain infrastructure and will serve both to increase the awareness of the final consumer and to speed up the identification of the goods to be collected in the event of a health risk. In addition, artificial

intelligence was applied to the image processing of processed food products, to increase production efficiency and food safety.

Project: Progetto Compagnia San Paolo IA - Circular Health. Salute Circolare per il settore agroalimentare. 2021-2024

Circular Health European Digital Innovation Hub (CHEDIH) is an Italian EDIH dedicated to the food and health industries. It is a one-shop to support the digitalisation of SMEs and public administrations concerned with food and health. It is active in Piedmont, the Aosta Valley and beyond. CHEDIH walks clients through all stages of their digital transition. Following a digital maturity level assessment, a customised roadmap is built, and the client is put in contact with technology providers in order to test technologies, gain access to technical expertise and initiate feasibility studies. The client's staff are trained in how to use the technologies. Clients are supported in their search for public and private funds and revision of their business plan. Agroinnova's role was to define the catalogue of services to provide to agrifood company.

Project: EU – CHEDIH. Circular Health European Digital Innovation Hub, 2022-2025.

Publications:

- Gullino ML (2023) Review: Women in plant disease management. *Front. Agron.* 5:1094239. doi: 10.3389/fagro.2023.1094239
- Gullino M. L., Pugliese M. (2023) – Diagnostica a distanza: opportunità e limiti. *Protezione delle Colture*, 5, 2-6.
- Pugliese M., Trucco F., Mezzalama M., Gullino M. L., Garibaldi A. (2023) - Sanità del mais a seguito di una gestione diversificata degli interventi di irrigazione. *Protezione delle Colture*, 2, 26.

Circular economy and wastewater

The project WALNUT aims to close the wastewater cycles for nutrient recovery. Wastewater streams are considered a promising resource to mitigate the soil nutrient imbalance and to recover nutrients for plant fertilising purposes. Nutrients from this large-scale recovery process can be used for bio-based fertilisers offering a new, circular, and sustainable model to tackle the limited nutrient-mineral reserves and its crucial environmental issues. These bio-based fertilisers will ensure food safety, minimise wastewater carbon footprint and protect nutrients natural reserves. As partner of the EU project WALNUT, AGROINNOVA carried out different activities to compile knowledge of recovered bio-based fertiliser technologies and products for improving soil and plant health. The

project focuses on technologies for recovering fertilizers from wastewater streams, and Agroinnova started greenhouse trials in 2023 applying the fertilizers developed by project partners, such as biosphosphate and algae-based fertilizers, and investigating their capacity to suppress soil-borne diseases on vegetable crops.

Project: EU - WalNUT. Closing wastewater cycles for nutrient recovery. 2022-2026.

Soil biodiversity

The project Excalibur plans to enhance the knowledge on soil biodiversity dynamics and its synergistic effects with prebiotic and probiotic approaches in horticulture, using a multi-actor approach. To pursue this aim, new multifunctional soil microbial inoculants (bio-inocula) and bio-effectors will be tested on three model crops of economic importance (tomato, apple, strawberry) under different experimental and open-field conditions across Europe, and the feed-feedback effect of/on native biodiversity monitored. To go beyond the multitude of studies on the links between soil biodiversity and plant health, Excalibur will develop a comprehensive strategy of soil management improving the effectiveness of biocontrol and bio fertilization practices in agriculture. As partner of the EU project EXCALIBUR, AGROINNOVA planned new multifunctional soil microbial inoculants (bio-inocula) and bio-effectors for 2 model crops of economic importance (es. tomato, strawberry), with attention on the links between soil biodiversity and plant health. A set of microbial antagonists (*Fusarium*, *Trichoderma*, and *Bacillus*) and biostimulants was evaluated during 2023 in greenhouse conditions on potted plants against soil-borne diseases of tomato and strawberry. *Fusarium oxysporum* MSA35, mycorrhiza consortia and an experimental biostimulant were among the most effective to reduce Fusarium wilt on tomato and Rhizoctonia crown and root rot on strawberry. The most effective products were applied in field trials on tomato and strawberry carried out in farms located in Moretta and Boves, and a reduction of soil-borne diseases was confirmed on tomato and strawberry, Rhizosphere samples were collected from the plants during field trials and DNA was extracted to be evaluated by qPCR and NGS during next year the impact of applied products on bacterial and fungal communities.

Project: EU - EXCALIBUR. Exploiting the multifunctional potential of belowground biodiversity in horticultural farming, 2019-2024.

Publications on ISI journals (see also Annex V):

- Bellini A., Gilardi G., Idbella M., Zotti M., Pugliese M., Bonanomi G., Gullino M. L. - (2023) - Trichoderma enriched compost, BCAs and potassium phosphite control Fusarium wilt of

lettuce without affecting soil microbiome at genus level. *Applied Soil Ecology*, 182 (4), 104678.

- Ptaszek M., Canfora L., Pugliese M., Pinzari F., Gilardi G., Trzciński P., Malusà E. (2023) - Microbial-Based Products to Control Soil-Borne Pathogens: Methods to Improve Efficacy and to Assess Impacts on Microbiome. *Microorganisms*, 11 (1), 224.
- Pugliese M., Gilardi G., Guarnaccia V., Garibaldi A., Gullino M.L. (2023) - First report of *Gnomoniopsis fragariae* causing leaf spots on strawberry in Italy. *Plant Disease*. 107, 9.

Post harvest diseases and Mycotoxins

Hazelnut nut defects

In 2023 the evaluation and identification of the 324 fungal isolates obtained in 2021 and 2022 in 3 different locations in Piedmont on hazelnuts showing defects and affecting the industrial quality was carried out. Pathogenicity of *Fusarium* spp., *Trichothecium* spp., *Diaporthe eres*, *D. rudis*, *Alternaria alternata*, *A. tenuissima*, *Aspergillus* spp. was carried out and the pathogenic strains were identified at a morphological and molecular level. A study carried out at 5°C, 10°C, 15°C, 20°C, 25°C, 30°C e 35°C to evaluate the temperature requirements and the growth rate of the pathogenic strains was carried out. The statistical analysis was not concluded yet. This study will complement the molecular analysis of the microbiome DNA extracted from sticky traps strips. DNA for 87 sticky strips was extracted and sent for sequencing. The analysis is undergoing to understand the fungal population dynamics during the cropping cycle and understanding when the main causal agents of the hazelnut defect occur in the field. This will allow the tuning of effective diseases management strategies.

Further surveys were conducted in north-western Italy to identify the causal agents of hazelnut rots. Typical symptoms of black rot, mold, and necrotic spots were observed on hazelnut nuts. The prevalent fungi isolated from symptomatic hazelnut kernels were *Diaporthe* spp. (38%), *Botryosphaeria dothidea* (26%), *Diplodia seriata* (14%), and other fungal genera with less frequent occurrences. Among 161 isolated *Diaporthe* spp., 40 were selected for further analysis. Based on morphological characterization and multi-locus phylogenetic analysis of the ITS, *tef1- α* , and *tub2*, seven *Diaporthe* species, *D. eres*, *D. foeniculina*, *D. novem*, *D. oncostoma*, *D. ravennica*, *D. rudis*. *D. sojiae*. and *D. eres* were the main species isolated from hazelnut rots, from mouldy nuts. Pathogenicity test performed on hazelnut nuts 'Tonda Gentile del Piemonte' showed that all the *Diaporthe* isolates were pathogenic on their original host.

Projects: “Nocciola di Qualità”, Piedmont Regional Government (2021-2024); “POSTFRUIT: Difesa post- raccolta dei prodotti ortofrutticoli” funded by Fondazioni Bancarie Cuneesi.

Collaborations: AGRION, Via Falicetto, 24 – 12030 Manta (CN)

Publications on ISI journal (see also Annex V):

- Waqas M., Guarnaccia V., Bardella S., Spadaro D. (2023) Molecular Characterization and Pathogenicity of *Diaporthe* Species Causing Nut Rot of Hazelnut in Italy. Plant Disease, in stampa. DOI: 10.1094/PDIS-01-23-0168-RE

Essential oils to control postharvest diseases.

The efficacy of biofumigation with thyme (*Thymus vulgaris*), savoury (*Satureja montana*), and basil (*Ocimum basilicum*) essential oils (EOs) at 1%, 0.5%, and 0.1% concentrations were tested against *B. cinerea*. In vitro, the results showed 100% growth inhibition at 1 % concentration for all oils. Subsequent biofumigation experiments on apples of cultivar ‘Opal’ with 1% EOs showed that, after 60 days of storage, thyme and savoury EOs significantly reduced grey mould rot incidence (average incidence 2% for both treatments) compared to the control (7%). Analyses of quality indicated slightly higher fruit firmness for 1% thyme at 30 d and slightly higher titratable acidity for 1% thyme and savoury at 60 d. Sampling of the atmosphere inside the cabinets was performed to characterize and quantify the volatile components of EOs released through biofumigation. Though thymol and p-cymene were the main components of thyme EO, the antimicrobial activity was mainly due to the presence of thymol and, to a lower extent, of carvacrol. In savoury EO, carvacrol and p-cymene were the main components, whereas in basil EO, linalool and estragole were mainly present. Metabarcoding analyses showed that the epiphytic microbiome had higher richness and evenness compared to their endophytic counterpart. By the end of shelf-life, treatments with thyme EO reduced *B. cinerea* abundance compared to the inoculated control for both endophytes (from 36.5 % to 1.5 %) and epiphytes (from 7.0% to 0.7%), while favouring a significant increase in *Penicillium* species both in endophytes (from 0.2 % to 21.5%) and epiphytes (from 0.5 % to 18.6 %). Results indicate that thyme EO (1%) and savoury EO (1%) are equally effective in hampering grey mould rot development in vivo.

Biofumigation with slow-release diffusers of essential oils (EOs) of basil, oregano, savoury, thyme, lemon, and fennel was assessed for the control of blue mould of apples, caused by *Penicillium expansum*. In vitro, the ability of the six EOs to inhibit the mycelial growth was evaluated at concentrations of 1.0, 0.5, and 0.1 %. EOs of thyme, savoury, and oregano, at all three concentrations, and basil, at 1.0 and 0.5 %, were effective in inhibiting the mycelial growth of *P.*

expansum. *In vivo*, disease incidence and severity were evaluated on 'Opal' apples artificially inoculated with the pathogen and treated at concentrations of 1.0 % and 0.5 % of EOs. The highest efficacy in reducing blue mould was observed with EOs of lemon and oregano at 1.0% after 60 days of storage at $1 \pm 1^\circ \text{C}$ (incidence of rot, 3 and 1 % respectively) and after further 14 days of shelf life at $15 \pm 1^\circ \text{C}$ (15 and 17 %). Firmness, titratable acidity, and total soluble solids were evaluated at harvest, after cold storage and after shelf life. Throughout the storage period, no evident phytotoxic effects were observed. EOs used were characterized through GC-MS to analyse their compositions. Moreover, the volatile organic compounds (VOCs) present in the cabinets were characterized during storage using the SPME-GC-MS technique. The antifungal effects of EOs were confirmed both *in vitro* and *in vivo* and the possible mechanisms of action are hypothesized. High concentrations of antimicrobial and antioxidant compounds in the EOs explain the efficacy of biofumigation in postharvest disease control.

The most common postharvest pathogens on nectarines are *Monilinia fructicola* and *M. laxa* the agents of brown rot. The efficacy of five essential oils (EOs) at 0.1, 0.5 and 1% concentration was evaluated *in vitro* against *M. fructicola* strain CVG1539 after 14 days at 25°C . Subsequently, biofumigation was realized with the three most effective EOs (fennel, basil, and lemon), this time at 2% concentration. Disease incidence was evaluated after a longer storage (28 days) at 1°C and after further 5 days shelf-life at 20°C . At the end of storage, nectarines treated with EOs showed a significant reduction in rots, which were caused by *Monilinia* spp. At the end of shelf-life, *Monilinia* spp., *Penicillium* spp., *Botrytis* spp., *Alternaria* spp., and *Rhizopus* spp. were isolated from the rots. Fruit quality and microbiome composition were analysed at harvest, after 28 days of storage, and after 5 days of shelf-life. The firmness in the treated fruits with EOs was higher compared to the untreated ones.

Project: "POSTFRUIT: Difesa post- raccolta dei prodotti ortofrutticoli" funded by Fondazioni Bancarie Cuneesi.

Collaborations: Fondazione AGRION

Publications on ISI Journals (see also Annex V):

- Buonsenso F., Schiavon G., Spadaro D. (2023) Efficacy and mechanisms of action of essential oils vapours against blue mould on apples caused by *Penicillium expansum*. International Journal of Molecular Sciences, 24 (3), 2900. DOI: 10.3390/ijms24032900

- Garello M., Schiavon G., Spadaro D. (2023) - Efficacy of biofumigation with essential oils in the control of postharvest rots on nectarines. *Acta Horticulturae*, 1363, 237-242. DOI: 10.17660/ActaHortic.2023.1363.35
- Schiavon G., Garello M., Prencipe S., Meloni G.R., Buonsenso F., Spadaro D. (2023) Essential oils reduce grey mould rot of apples and modify the fruit microbiome during postharvest storage. *Journal of Fungi*, 9 (1), 22. DOI: 10.3390/jof9010022

Antagonistic microorganisms to control postharvest diseases.

White haze is an apple blemish that reduces the commercial value of affected fruit. We selected two *Aureobasidium pullulans* strains (AP2 and PL5) and tested them against white haze of apple, caused by *Golubevia*, *Entyloma* and *Tilletiopsis*. At the end of shelf-life, both strains showed an efficacy comparable to the chemical control treatment in preventing white haze development. Microbiota analysis composition shows that these strains present a good proliferation on treated fruit, both epiphytically and endophytically. The presence of *A. pullulans* does not correlate with a decreased presence of white haze genera, which might suggest a more complex action mechanism. We aimed to evaluate the efficacy of treatments with antagonistic yeasts to control brown rot of nectarines. A screening trial was set up by treating inoculated fruits with 14 yeast strains. The most effective strains (MS, *Metschnikowia* sp., AP47, *M. fructicola*, FR4A, *Aureobasidium* sp.) were tested in semi-commercial conditions. Fruits were maintained in storage rooms at 1 °C for 28 days, followed by 4 days of shelf-life at 25 °C. After storage, all treatments showed a significant rot reduction compared to the control. The efficacy of MS strain was comparable to the chemical control treatment, making the antagonist as competitive as fungicides. All strains maintained a significant rot reduction at the end of shelf-life. The evaluation of postharvest quality parameters, including firmness, total soluble solids and titratable acidity showed that none of the three tested yeasts affected nectarine quality. A metabarcoding analysis was conducted to evaluate the effect of the treatments on the microbial population of the nectarines.

The efficacy of antagonistic yeast strains in reducing grey mould of grapes in postharvest was evaluated. Two trials were set up by treating inoculated grape bunches with yeast cell suspensions. Treatments showed significant rot reductions compared to the control. The efficacy of MS strain (*Metschnikowia* sp.) was comparable to the chemical treatment in both trials at all storage times. Moreover, a metabarcoding analysis was conducted to evaluate the effect of the treatments on the microbial population of grapes. This study provides new insights for the development of sustainable strategies to reduce production losses.

Project: "POSTFRUIT: Difesa post- raccolta dei prodotti ortofrutticoli" funded by Fondazioni Bancarie Cuneesi.

Collaborations: AGRION, Via Falicetto, 24 – 12030 Manta (CN)

Publications on ISI Journals (see also Annex V):

- Garello M., Schiavon G., Spadaro D. (2023) Efficacy of postharvest application of *Aureobasidium pullulans* in the control of white haze on apples and effect on the fruit mycobiome. IOBC-WPRS Bulletin 165, 131-133.
- Spadaro D., Remolif G., Garello M., Prencipe S., Gonella E., Giacosa S., Englezos V. (2023) Efficacy of antagonistic yeasts in reducing grey mould on grape and effect on the fruit microbiome. IOBC-WPRS Bulletin 165, 142-143.

KNOWLEDGE AND TECHNOLOGY TRANSFER

The project SIMBIOSI BIO-SAL intends to improve the resilience and sustainability of agroecosystems through so-called "nature-based" solutions, aimed at preserving and enhancing widespread naturalness, biodiversity, and ecological processes typical of agricultural agroecosystems, to improve the safety and healthiness of local production. AGROINNOVA started an "oasis of biodiversity" in Feletto, with sustainable cultivation of fruit and vegetables, at the "Campo Aperto" cooperative. Organized training courses (20 hours) for hobby farmers in Saluzzo on sustainable crop protection and training courses (20 hours) for schoolteachers in Saluzzo on sustainable crop protection.

Project: Progetto Compagnia San Paolo – SIMBIOSI BIO-SAL. Biodiversità e salute delle piante. 2024-2025

In 2023 a training activity was carried out for two senior technicians of the CREA - Centro di Ricerca Cerealicoltura e Colture Industriali of the branch in Vercelli to test rice seed for the identification and quantification of *Fusarium fujikuroi* with a LAMP method. The activity consisted of two steps: theory and 1 day practice in the molecular laboratory of AGROINNOVA DIAGNOSTICS. The technique is applied to seed for planting. The relevance of the use of this pre-planting test is the possibility to evaluate quickly the phytosanitary status of the seed lot, the efficacy of seed treatments and in variety selection process to eliminate susceptible lines.

COMMUNICATION & DISSEMINATION

AGROINNOVA scientists participated to several national and international scientific congresses during the year as invited speakers or delivering oral presentations (Annex VI) as well as events of public engagement (Annex VII)

AGROINNOVA continues to publish the Journal on crop protection “Protezione delle colture”.

CONCLUDING REMARKS

The activities of AGROINNOVA – Interdepartmental Centre are pursuing the activities of AGROINNOVA – Centre of Competence. During the first year of activity, 7 researchers participated to the activities of the Centre. Thirty-six publications were published on peer-reviewed ISI journals. The researchers of AGROINNOVA participated with invited, oral and poster presentations to several international and national congresses to present the results of the research activity. The Centre was able to attract funding from the EU, as well as from regions and bank foundations. The growing interest of the private companies in the activities of the Centre is evidenced by the high number of research contracts. AGROINNOVA established new collaborations and networks with institutional and private partners in Italy and worldwide.

Grugliasco, 31 December 2023

The Director

Prof. Alberto Alma

ANNEXES

ANNEX I - The management committee

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*On board until October 2023; replaced by Marco Beccuti, Associate Professor, Computer Science Department

ANNEX II – The Scientific Committee

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ANNEX III – The team

AGROINNOVA UNIVERSITY STAFF

SURNAME AND NAME	QUALIFICATION AND ROLE
Garibaldi Angelo	Emeritus Professor, President
Alberto Alma	Full Professor, Director
Monica Mezzalama	Associate Professor, Deputy Director
Paolo Gonthier	Full Professor, collaborator
Davide Spadaro	Full Professor, collaborator
Vladimiro Guarnaccia	Associate Professor, collaborator
Massimo Pugliese	Associate Professor, collaborator
Guglielmo Leone	Assistant professor, collaborator
Gilardi Giovanna	Graduate technician, PhD
Bertetti Domenico	Graduate technician
Zerbini Gabriele	Technician
Valerio Antonella	Chief secretary

ADDITIONAL STAFF SUPPORTED THROUGH PROJECTS

SURNAME AND NAME	ROLE
Vasileiadou Athina	Laboratory technician
Dardani Greta	PhD student
Sanna Martina	PhD student
Valfrè Paolo	PhD student
Carlo Roperto	PhD student
Luca Alfarano	PhD student
Trucco Federico	Fellow
Izabella Lundborg	Fellow
Giuseppe Caputo	Fellow
Manfrin Samuel	Field technician

INTERNATIONAL COLLABORATORS AND VISITORS

SURNAME AND NAME	QUALIFICATION	INSTITUTION	FROM - TO	AREA OF ACTIVITIES
Lundborg Izabella	Fellow	Swedish University of Agricultural Sciences, Sweden	June 2022 – Feb 2024	Sustainable crop protection of vegetable crops
Ricardo Felipe Lima de Souza	PhD student	Instituto Valenciano de Investigaciones Agrarias	May – October 2023	Postharvest disease control
Oluwole Ogutande	Visiting Scientist	International Institute for Tropical Agriculture (IITA) Ibadan, Nigeria	December 4-16, 2023	Diagnostics and molecular detection of plant pathogens

ANNEX IV - List of projects 2023

FUNDING BODY	TITLE and Responsible	DURATION AND ROLE
European Union –H2020	Exploiting the multifunctional potential of belowground biodiversity in horticultural farming (EXCALIBUR) - Massimo Pugliese	2019-2024 PARTNER
	WalNUT – Closing Waste water cycles for nutrient recovery - Massimo Pugliese	2022-2025 PARTNER
European Union – Digital Europe Programme	CHEDIH - Circular Health European Digital Innovation Hub - Massimo Pugliese	2023-2025 PARTNER
Italian Ministry of Health	“ReNEWater: OFood safety: study, improvement and application of systems for the reuse of purified water in agriculture, for zootechnical purposes and in the horticultural supply chain” - Massimo Pugliese	2022-2024 PARTNER
PSR- Rural Development Program -Piedmont Regional Government	VI.P. - Viticoltura di Precisione (Precision viticulture) - Massimo Pugliese	2020-2023 PARTNER
	MONITORA - Advanced monitoring service for irrigation and sustainable fertilization, and integrated control for open field vegetables - Massimo Pugliese	2020-2023 PARTNER
AGER – Agroalimentare e ricerca.	From SOil to Soil: origin and remediation to KIWIfruit Vine Decline Syndrome (SOS-KIWI)- Davide Spadaro	2023-2027 PARTNER
Piedmont Regional Government	“Nocciola di Qualità” – Hazelnut quality. Targeting the problems affecting the industrial quality of hazelnut. – Monica Mezzalama	2021-2024 PARTNER
Compagnia di San Paolo	CH4I - Circular Health for Industry Development of a traceability system for agrifood products using blockchain technology. Development of AI models to monitor the risk of plant disease outbreaks. - Massimo Pugliese	2020-2023 PARTNER
Compagnia di San Paolo	BIO-SAL “Biodiversità e salute delle piante” (Biodiversity and Plant Health) - Massimo Pugliese	2023-2025 PARTNER
CRC Foundation (Fondazione Cassa di Risparmio di Cuneo)	SFIDA – Low environmental impact management strategies for the horticultural sector (Strategie di difesa a basso impatto ambientale per la filiera orticola) - Massimo Pugliese	2019-2023 PARTNER
	VITE 4.0. Innovation in plant disease management for viticulture environmental impact reduction (Innovazioni nella difesa fitosanitaria per la riduzione dell’impatto ambientale della viticoltura) - Massimo Pugliese	2020-2023 PARTNER
Fondazione Cassa di Risparmio di Saluzzo	Innovative diagnostics of plant diseases with particular reference to remote and on site diagnostics (Diagnostica innovativa delle malattie delle piante con particolare riferimento alla diagnostica a distanza e di campo) – Vladimiro Guarnaccia	2021-2024 COORDINATOR

FUNDING BODY	TITLE and Responsible	DURATION AND ROLE
Bank Foundations of the Cuneo Province: Fondazione Cassa di Risparmio di Cuneo Fondazione Cassa di Risparmio di Fossano Fondazione Cassa di Risparmio di Saluzzo Fondazione Cassa di Risparmio di Savigliano	POST-FRUIT: post-harvest protection of fruit and vegetables Vladimiro Guarnaccia	2020-2023 PARTNER
Fondazione Cassa di Risparmio di Saluzzo	Innovative diagnostics of plant diseases with particular focus on remote and field diagnostics – Vladimiro Guarnaccia	2021-2024 COORDINATOR
KeyPlex (private company)	Etiology and control of Colletotrichum diseases on citrus in Florida - Vladimiro Guarnaccia	2022-2024 COORDINATOR
RANDA (The Royal and Ancient Golf Club of St Andrews)	“Effects of biostimulants and microorganisms against the most common turfgrass diseases in Italy” – Massimo Pugliese	2023-2025 PARTNER
Italian Ministry for Research	Management models to promote sustainability and resilience of agricultural production systems. PNRR AgriTech Spoke 6 – Massimo Pugliese	2023-2025
CREA	Evaluation of the varietal susceptibility of rice to <i>Pyricularia oryzae</i> – Davide Spadaro	2022-2023
BIOLCHIM S.p. A.	Efficacy of prebiotics and probiotics in the control of kiwifruit vine decline – Davide Spadaro	2022-2024
CEAP – Bacardi	Phytosanitary concerns of herbal plant species in Piedmont: identification of the causal agents and evaluation of the seed and propagation material health – Davide Spadaro	2023-2024
SAPISE -Sardo Piemontese Sementi	Susceptibility of rice to <i>Fusarium fujikuroi</i> and <i>Pyricularia oryzae</i> – Davide Spadaro	2022-2024
Several seed and agricultural companies	Evaluation of disease resistance of new varieties of vegetable and cereal crops – Giovanna Gilardi and Massimo Pugliese	2023
RI.NOVA Coop.	“Zucchini-Bio” Varietal innovation to support the production chain of traditional zucchini of Bologna, maintaining typicality and sustainability even in the era of climate change” - Massimo Pugliese and Giovanna Gilardi	

ANNEX V– List of publications 2023 (alphabetical order)

1. Aiello, D., Bregant, C., Carlucci, A., Guarnaccia, V., Gusella, G., Linaldeddu, B. T., ... Polizzi, G. (2023). Current status of Botryosphaeriaceae species in Italy: Impacts on agricultural crops and forest ecosystems. *Phytopathologia Mediterranea*, 62(3), 381-412.
2. Bellini A., Gilardi G., Idbella M., Zotti M., Pugliese M., Bonanomi G., Gullino M. L. - (2023) - *Trichoderma* enriched compost, BCAs and potassium phosphite control *Fusarium* wilt of lettuce without affecting soil microbiome at genus level. *Applied Soil Ecology*, 182 (4), 104678.
3. Bertetti D., Rettori A., Martinis R., Guarnaccia V., Tabone G., Garibaldi A., Gullino M. L. (2023) - First Report of *Neofusicoccum parvum* causing stem cankers and woody rot on *Eucalyptus globulus* in France. *Plant Disease*, 107, 2548.
4. Bosco S., Guarnaccia V., Mezzalama M., Spadaro D. (2023) Selection of endophytes isolated from Italian rice cultivars as biocontrol agents against *Fusarium fujikuroi*. *Journal of Plant Pathology*, 105, 100.
5. Buonsenso F., Schiavon G., Spadaro D. (2023) Efficacy and mechanisms of action of essential oils vapours against blue mould on apples caused by *Penicillium expansum*. *International Journal of Molecular Sciences*, 24 (3), 2900. DOI: 10.3390/ijms24032900
6. Dardani, G., Guarnaccia, V., Nari, L. Testempasis, S. I., Karaoglanidis, G. S., Gullino, M. L. (2023). Identification of pathogens causing brown rot of stone fruit in Cuneo province (Italy) and assessment of sensitivity to azoxystrobin, cyprodinil, fenhexamid, fludioxonil, and tebuconazole. *Phytopathologia Mediterranea*, 62(3), 455-465.
7. Dardani, G., Mugnai, L., Bussotti, S., Gullino, M. L., & Guarnaccia, V. (2023). Grapevine dieback caused by Botryosphaeriaceae species, *Paraconiothyrium brasiliense*, *Seimatosporium vitis-viniferae* and *Truncatella angustata* in Piedmont: characterization and pathogenicity. *Phytopathologia Mediterranea*, 60, 283-306.
8. Garelo M., Schiavon G., Spadaro D. (2023) - Efficacy of biofumigation with essential oils in the control of postharvest rots on nectarines. *Acta Horticulturae*, 1363, 237-242. DOI: 10.17660/ActaHortic.2023.1363.35
9. Garelo M., Schiavon G., Spadaro D. (2023) Efficacy of postharvest application of *Aureobasidium pullulans* in the control of white haze on apples and effect on the fruit mycobiome. *IOBC-WPRS Bulletin* 165, 131-133.

10. Garibaldi A., Bertetti D., Martino I., Gullino M. L. (2023) - First Report of Botrytis Blight Caused by *Botrytis cinerea* on *Plectranthus scutellarioides* in Italy. Plant Disease, in press.
11. Garibaldi A., Bertetti D., Martino I., Luongo I., Gullino M. L. (2023) - First Report of *Heterophoma verbasci-densiflori* on *Verbascum chaixii* "Album" in Italy. Journal of Plant Pathology, in press.
12. Garibaldi A., Bertetti D., Tabone G., Gullino M. L. (2023) - First Report of Leaf Spots Caused by *Alternaria alternata* on *Melissa officinalis* in Italy. Plant Disease, 107, 1634.
13. Garibaldi A., Bertetti D., Tabone G., Luongo I., Gullino M. L. (2023) - First Report of Leaf Spots Caused by *Alternaria alternata* on *Hydrangea paniculata* in Italy. Journal of Plant Pathology, 105, 599.
14. Garibaldi A., Bertetti D., Tabone G., Luongo I., Gullino M. L. (2023) - First Report of Root Rot Caused by *Globisporangium sylvaticum* on *Anemone japonica* in Italy. Plant Disease, 107, 2267.
15. Garibaldi A., Tabone G., Luongo I., Gullino M. L. (2023) - First Report of Leaf Spots and Stem Rot Caused by *Diaporthe eres* on *Hydrangea macrophylla* in Italy. Plant Disease, 107, 1942.
16. Garibaldi A., Tabone G., Luongo I., Gullino M. L. (2023) - First Report of *Pythium irregulare* causing root rot on *Digitalis purpurea* in Italy. Journal of Plant Pathology, 105, 313.
17. Garibaldi A., Tabone G., Luongo I., Gullino M. L. (2023) - First Report of *Cladosporium cladosporioides* causing leaf spot on *Veronica spicata* in Italy. Journal of Plant Pathology, 105, 357.
18. Gilardi G., Tabone G., Gullino M.L., Garibaldi A. (2023) Effect of the use of biocontrol agents and resistance inducers against race 1 of *Fusarium oxysporum* f. sp. *lactucae* on lettuce in a simulated climate change scenario. Journal of Plant Pathology, in press.
19. Grella M., Gioelli F., Marucco P., Zwertvaegher I., Mozzanini E., Pittarello M., Balsari P., Fountas S., Nuyttens D., Mezzalama M., Pugliese M. (2023). Assessment of microbial biocontrol agent (BCA) viability to mechanical and thermal stress by simulating spray application conditions. Pest Management Science, 79 (11), 4423-4438.
20. Guarnaccia, V., Remolif, G. M., Nari, L., Gualandri, V., Angeli, D., Oettl, S., ... & Spadaro, D. (2024). Characterization of fungal species involved in white haze disorder on apples in Northern Italy and description of *Golubevia mali* sp. nov. and *Entyloma mali* sp. nov. Postharvest Biology and Technology, 209, 112678.

21. Leonardi, G.R., Aiello, D., Camilleri, G., Piattino, V., Polizzi, G., & Guarnaccia, V. (2023). A new disease of kumquat (*Fortunella margarita*) caused by *Colletotrichum karsti*: twig and branch dieback. *Phytopathologia Mediterranea*, 333-348.
22. Mancuso T., De Cianni R., Di Vita G.A., Spada E., Brun F., Spadaro D., Zanchini R. (2023) Understanding Consumers' Perceptions of Tomato Agricultural Innovation: Exploring the Nexus between Sustainability, Health and Consumer Beliefs. *Journal of Cleaner Production*, 435, 140528. DOI: 10.1016/j.jclepro.2023.140528
23. Martino, I., Agustí-Brisach, C., Nari, L., Gullino, M. L., & Guarnaccia, V. (2023). Characterization and pathogenicity of fungal species associated with dieback of apple trees in Northern Italy. *Plant Disease*, (in press).
24. Moinè A., Pugliese M., Monchiero M., Gribaudo I., Gullino M. L., Pagliarani C., Gambino G. (2023). Effects of fungicide application on physiological and molecular responses of grapevine (*Vitis vinifera* L.): a comparison between copper and sulfur fungicides applied alone and in combination with novel fungicides. *Pest Management Science*, 79 (11), 4569-4588.
25. Prencipe S., Meloni G.R., Nari L., Schiavon G., Spadaro D. (2023) - Pathogenicity, molecular characterization and mycotoxigenic potential of *Alternaria* spp. agents of black spots on fruit and leaves of *Pyrus communis* in Italy. *Phytopathology*, 113 (2), 309-320. DOI: 10.1094/PHTO-03-22-0103-R
26. Prencipe S., Schiavon G., Rosati M., Nari L., Schena L., Spadaro D. (2023) Different species of *Phytophthora* are involved in the establishment and development of Kiwifruit Vine Decline Syndrome. *Microorganisms*, 11, 216. DOI: 10.3390/microorganisms11010216
27. Prencipe S., Valente S., Nari L., Spadaro D. (2023) - A quantitative real-time PCR assay for early detection and quantification of *Ramularia mali*, an emerging pathogen of apple causing dry lenticel rot. *Plant Disease*, 107(5), 1399-1407. DOI: 10.1094/PDIS-07-22-1586-RE
28. Ptaszek M., Canfora L., Pugliese M., Pinzari F., Gilardi G., Trzciński P., Malusà E. (2023) - Microbial-Based Products to Control Soil-Borne Pathogens: Methods to Improve Efficacy and to Assess Impacts on Microbiome. *Microorganisms*, 11 (1), 224.
29. Pugliese M., Gilardi G., Guarnaccia V., Garibaldi A., Gullino M.L. (2023) - First report of *Gnomoniopsis fragariae* causing leaf spots on strawberry in Italy. *Plant Disease*. 107, 9.
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Other publications

1. Bertetti D., Rettori A., Martinis R., Guarnaccia V., Tabone G., Gullino M. L., Garibaldi A. (2023) - Presenza di *Neofusicoccum parvum* su due piante ornamentali in Francia: *Schinus molle* ed *Eucalyptus globulus*. Protezione delle colture, 16 (3), 15-18.
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3. Bertetti D., Martino I., Gullino M. L., Garibaldi A. (2023) - Presenza di *Botrytis cinerea* su piante di *Plectranthus scutellarioides* in Italia. Protezione delle colture, 16 (3), 19-20.
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5. Bertetti D., Tabone G., Gullino M. L., Garibaldi A. (2023) - Presenza di una ruggine causata da *Coleosporium campanulae* su *Campanula trachelium* in Italia. Protezione delle Colture, 16 (2), 16-17.

6. Bertetti D., Tabone G., Luongo I., Gullino M. L., Garibaldi A (2023) - Attacchi di *Alternaria alternata* su *Melissa officinalis* in Italia. *Protezione delle colture*, 16 (3), 11-12.
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9. Garibaldi A., Bertetti B., Luongo I., Martino I., Gullino M. L. (2023) – Presenza di *Heterophoma verbasci-densiflora* su semenzali di *Verbascum chaixii* “Album” in Italia. *Protezione delle Colture*, 16 (4), 18-19.
10. Gilardi G., Pugliese M., Vasileiadou A., Valfrè P., Giordano R., Carli G., Garibaldi A., Gullino M. L. (2023) – Risultati di prove sperimentali sulla difesa dalla tracheofusariosi e dal mal bianco del pomodoro. *Protezione delle Colture*, 16 (3), 2-8.
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12. Gullino M. L., Pugliese M. (2023) – Impiego di mezzi biologici nella difesa dai patogeni fungini: risultati, problemi e prospettive. *Protezione delle Colture*, 16 (5), 2-4.
13. Gullino M. L., Pugliese M., Pasquali M. (2023) – Salute circolare: un nuovo modo di intendere la salute e il ruolo della salute delle piante. *Protezione delle Colture*, 16 (5), 5-8.
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16. Nari L., Berra L., Bardi L., Monaco S., Mandala C., Morone C., Spadaro D., Guaschino M., Giorgi V., Neri D. (2023) Moria, misure agronomiche unico strada percorribile. *Terra e Vita* 64 (31), 40-43.
17. Pugliese M., Gilardi G., Gullino M. L., Garibaldi A. (2023) – Cambiamenti climatici e malattie delle piante. *Protezione delle Colture*, 16 (2), 4-8.

18. Pugliese M., Gilardi G., Guarnaccia V., Vasileiadou A., Valfrè P., Tabone G., Garibaldi A., Gullino M. L. (2023) – Prime osservazioni di *Gnomoniopsis fragariae* responsabile di necrosi fogliari e dei piccioli su fragola in Italia. *Protezione delle Colture*, 16 (4), 20-21.
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21. Pugliese M., Trucco F., Gullino M. L., Garibaldi A. (2023) – Efficacia di strategie di difesa contro la ticchiolatura del melo che prevedono l'uso di sistemi di supporto decisionale e di mezzi di lotta alternativi ai fungicidi candidati alla sostituzione. *Protezione delle Colture*, 16 (2), 20
22. Pugliese M., Trucco F., Gullino M. L., Garibaldi A. (2023) – Applicazione di raggi UV-C in vigneto per il contenimento di peronospora e oidio. *Protezione delle Colture*, 16 (2), 24-25.
23. Pugliese M., Trucco F., Mezzalama M., Gullino M. L., Garibaldi A. (2023) - Sanità del mais a seguito di una gestione diversificata degli interventi di irrigazione. *Protezione delle Colture*, 16 (2), 26.
24. Pugliese M., Valfrè P., Gilardi G., Gullino M. L., Garibaldi A. (2023) – Efficacia di fertilizzanti e biostimolanti sul contenimento di *Rhizoctonia solani* su fragola. *Protezione delle Colture*, 16 (2), 27.
25. Tabone G., Luongo I., Gullino M. L., Garibaldi A. (2023) – Presenza di *Cladosporium cladosporioides* su *Veronica spicata* in Italia. *Protezione delle Colture*, 16 (3), 12-14.
26. Tabone G., Luongo I., Gullino M. L., Garibaldi A. (2023) – Presenza di *Diaporthe eres* su *Hydrangea macrophylla* in Italia. *Protezione delle Colture*, 16 (3), 13-15.
27. Vasileiadou A., Gilardi G., Pugliese M., Gullino M. L., Garibaldi A. (2023) – Opportunità per una difesa sostenibile utilizzando microrganismi e induttori di resistenza in fuori suolo. *Protezione delle Colture*, 16 (4), 6-10.

ANNEX VI - PARTICIPATION OF AGROINNOVA SCIENTISTS TO NATIONAL AND INTERNATIONAL CONGRESSES

Congress	Place and date	Scientist	Title and type of presentation
ECFG16 - 16th European Conference on Fungal Genetics	Innsbruck, 5-8 March 2023	Davide Spadaro	The epidemiology of fungal pathogens of apples unveiled by fruit microbiome: the case of dry lenticel rot and white haze (P)
		Martino I., Guarnaccia V.	Species diversity in <i>Colletotrichum</i> causing anthracnose on Lamiaceae and SYBR Green qPCR assay for the species-specific detection of <i>C. ocimi</i> – O
16th European Fusarium Seminar	Rome, 12-15 June 2023	Giulia Remolif	Efficacy of postharvest application of <i>Aureobasidium pullulans</i> in the control of white haze on apples and effect on the fruit mycobiome (O)
		Davide Spadaro	Efficacy of antagonistic yeasts in reducing grey mould on grape and effect on the fruit microbiome (O)
		Simone Bosco	Screening of endophytes from rice cultivars as biocontrol agents against <i>Fusarium fujikuroi</i> (O)
		Davide Spadaro	Different species of <i>Fusarium</i> cause vascular wilt of lettuce: molecular and pathogenicity approach (O)
12th International Congress of Plant Pathology	Lyon, 20-25 August 2023	Davide Spadaro	Microbiomes: an important tool to elucidate the epidemiology of postharvest pathogens (I) Innovative sustainable technologies to extend the shelf life of perishable mediterranean fresh fruit, vegetables, and aromatic plants and to reduce waste: the experience of PRIMA STOPMEDWASTE project (P) Efficacy of a zero-residue strategy against field and postharvest diseases on strawberries (P)
		Micol Guaschino	The role of the oomycete <i>Phytophthium vexans</i> as a biotic stress component of Kiwifruit Vine Decline Syndrome in Italy (O) Characterization of the soil, rhizosphere and root microbiome associated to kiwifruit vine decline syndrome in Italy (P)
		Giulia Remolif	Efficacy of antagonistic yeasts in the control of brown rot of nectarines and effect on fruit microbiome (O) Efficacy of biofumigation with essential oils in the control of postharvest rots of nectarines (P)
		Guarnaccia V.	Fungal trunk diseases of fruit trees in Europe: pathogens, spread and future directions (O)

		Gullino M. L., Gilardi G., Pugliese M.	Emerging diseases in the vegetable sector: challenges and perspectives (I)
		Pugliese M.	Effect of compost and biocontrol agents on lettuce and tomato fusarium wilts and on rhizosphere microbiome (P)
		Pugliese M.	Integrated and biological management strategies against powdery and downy mildews on grape: recent results from trials carried out in Italy (P)
		Pugliese M.	Biocontrol of <i>Rhizoctonia solani</i> on strawberry in greenhouse by experimental antagonists (P)
XXVIII Congress of the Italian Phytopathological Society	Napoli, 18-20 September 2023	Martina Sanna	Characterization of <i>Fusarium</i> species diversity causing crown and stalk rot on maize in northern Italy (O)
		Vladimiro Guarnaccia	Characterization of the causal agents, epidemiology and biological control of white haze on apple (O)
		Davide Spadaro	Selection of endophytes isolated from Italian rice cultivars as biocontrol agents against <i>Fusarium fujikuroi</i> (P)
		Marco Garelo	Mycotoxigenic potential of <i>Penicillium</i> species isolated from fresh chestnuts and derived products (P)
		Dardani G.	Botryosphaeriaceae species, <i>Paraconiothyrium brasiliense</i> , <i>Seimatosporium vitis</i> and <i>Truncatella angustata</i> associated with grapevine dieback in Piedmont: characterization and pathogenicity – O
		Martino I.	Characterization of fungal pathogens associated with fungal trunk diseases of hazelnut in Northern Italy – O
		P. Valfrè	Effect of antagonistic microorganisms and biostimulants for managing Fusarium wilt of tomato under greenhouse conditions (P)
IOBC/WPRS Working Group “Integrated Protection in Viticulture”	Logrono, Spain, 3 – 5 Oct, 2023	Guarnaccia V.	Grapevine dieback caused by Botryosphaeriaceae species <i>Paraconiothyrium brasiliense</i> , <i>Seimatosporium vitis</i> and <i>Truncatella angustata</i> in Piedmont: characterization and pathogenicity – (O)
XXVI AIV Conference – Energy Transition and Environmental Sustainability: Materials, Processes and Devices for Research and	Rome, 7-10 Novembre 2023	Davide Spadaro	Innovative diagnostics for plant pathogen detection (I)

Industrial Applications			
53 INCONTRI FITOIATRICI	Torino, 29 March 2023	Pugliese M.	Cambiamenti climatici e malattie delle piante (O)
X International Symposium on Soil and Substrate Disinfestation	Almeria, Spain, 6-8 June 2023	Pugliese M.	Effect of compost and biocontrol agents on lettuce and tomato Fusarium wilts and on rhizosphere microbiome (O)
			Efficacy of microorganisms against <i>Rhizoctonia</i> crown and root rot on strawberry in greenhouse (P)
			Efficacy of microorganisms against Fusarium wilt on tomato in greenhouse (P)

I = invited speaker

O = oral presentation

P = poster presentation

ANNEX VII - Outreach activities

EVENT	PLACE	SCIENTIST	Type of presentation	DATE
Elementi di didattica per insegnare il suolo	Verbania (VB)	Massimo Pugliese	Oral	May 24, 2023
Monferrato Green Farm	Casale Monferrato (AL)	Massimo Pugliese	Oral	September 29, 2023
Monferrato Green Farm	Casale Monferrato (AL)	Monica Mezzalama	Oral-round table	October 1, 2023
Elementi di didattica per insegnare il suolo	Biella (BI)	Massimo Pugliese	Oral	Nov 29, 2023