FINAL REPORT

In this research project, internationally novel epidemiological research was carried out under pre- and postharvest conditions, exploring the epidemiological features of fruit disease interactions at individual and population levels. The aim was to develop much more effective disease management models against some of the major fruit fungal diseases, such as powdery mildews, *Venturia* sp., *Monilinia* sp., *Blumeriella jaapii*, *Wilsonomyces carpophilus* (syn. *Stigmina carpophila*) and postharvest disease complexes. Through this research, we effectively increased the sensitivity/accuracy, safety and economic profitability of plant disease control in time and space.

The specific results were sorted into four work packages, which aligned with the main objectives of this research project: I) plant organ development from unfolding to harvest or from harvest to storage; II) study of the emergence and the progression of diseases appear jointly, and the detailed investigation of major epidemiological interactions; III) disease interactions under mixed cultivar planting systems (MCPS); and IV) development of disease warning models and environmentally friendly disease management strategies based on organ-specific disease interactions and improved MCPS.

This final report presents results and subsequent publications from 2019 to 2024, organized according to the four main work packages:

I) Plant organ development from unfolding to harvest or from harvest to storage

In this work package, the components that influence plant organ development, with a key role in affecting disease development, were selected. The investigations were classified into two groups: i) preharvest trials and ii) postharvest trials.

I/a) Preharvest investigations

In preharvest, many technological factors had been investigated previously; however, the most variable and complex components were orchard training systems, cultivars with disease resistance, and the effects of climate change. Therefore, these became the focus of this work package.

I/a/i) orchard training system component

Orchard training systems have the potential to successfully reduce disease development, but the plant organ characteristics underlying this effect had not been evaluated. Therefore, we determined plant organ development at the apple fruit maturity stage in three orchard training systems (Oblique Palmette - 1250 trees ha^{-1}, Bibaum - 1923 trees ha^{-1} and slender spindle - 1666 trees ha^{-1}) by analyzing 20 fruit parameters. These parameters included 9 related to fruit yield, 8 to physicochemical properties, and 4 to antioxidant capacity, as well as their interrelationships, using the scab-susceptible cultivar ‘Royal Gala’ (1). Most of the 20 parameters were significantly affected by the training systems. The results indicated that the long-term proper functioning of the fruit organ was highly dependent on the fruit's high antioxidant capacity. Additionally, the findings showed that antioxidant capacity differed significantly among training systems, indicating that not all training systems have an equal ability to reduce disease development in plant organs.

I/a/ii) host resistance component

As antioxidant capacity-related parameters play an essential role in plant organ health, our research further focused on developing reliable and suitable extraction methods (water

control, pectinase, two approaches using ethanol, methanol and methanol + acetone) for measuring antioxidant capacity and polyphenol content, specifically on scab-resistant apple cultivars (‘Fujion’, ‘Gaia’, ‘Isaaq’ and ‘Smeralda’) (2). These cultivars have essential genetic traits that can delay scab development in organic orchards. Results showed that the pectinase extraction method was the most stable option for measuring antioxidant capacity parameters in apple flesh across all scab-resistant apple cultivars. Positive correlations were also observed between antioxidant content and the resistance of apple cultivars to apple scab. Our study was the first to connect various antioxidant capacity extraction methods to specific scab-resistant apple cultivars (2).

I/a/iii) climate change component

Climate change can substantially influence the dormancy and chilling periods of temperate fruit trees, which can have a significant impact on yield stability and forecasting models. Our analyses revealed that global warming has led to a deficit in chill and dormant periods for temperate fruit trees during winter, which may become a limiting factor in the future (3). Thus, the increasing rate of climate change requires improvements in certain managing tools, including i) breeding new, climate-smart cultivars with more effective disease resistance; and ii) reconstructing dormancy and chilling forecasting models, which will also influence the accuracy of current disease warning models based on organ-specific disease interactions.

I/b) Postharvest investigations

In postharvest trials, we examined the effect of materials that i) play roles in plant defense mechanisms through the systemic acquired resistance (SAR) pathway, such as salicylic acid and/or methyl jasmonate (4,5); and ii) serve as easy and cost-effective options for food preservation, such as sodium benzoate (6).

I/b/i) salicylic acid and/or methyl jasmonate

As apricot storability is one of the major challenges, we focused on apricot fruit cold storage and shelf-life conditions to prolong fruit quality by reducing postharvest losses, including fruit decay. To better understand postharvest quality loss due to fruit decay, we assessed 8 parameters related to antioxidant properties and enzyme activities under temporal development time-regimes using previously determined effective concentrations of methyl jasmonate (MeJA) and salicylic acid (SA) (4). Results showed that MeJA and SA significantly decreased fruit decay at all time-regimes for both storage conditions. Additionally, MeJA- and SA-treated fruits exhibited increased antioxidant capacity, phenolic compounds, and enzyme activities of phenylalanine ammonia-lyase (PAL), peroxidase (POD), and superoxide dismutase (SOD) at all dates of both storage treatments. These parameters were strongly interconnected, as revealed by principal component analysis (PCA) PC1. Our findings confirmed that apricot fruit decay during storage can be significantly reduced by MeJA and SA treatments, as they enhance antioxidant properties, enzyme activities, and the plant defense mechanisms of the fruit.

In our experiments, the primary fruit decay component was brown rot caused by *Monilinia laxa*. Therefore, we specifically targeted our next MeJA and SA postharvest experiments on this pathogen under shelf-life storage conditions by applying treatments to *M. laxa*-inoculated and non-inoculated apricot fruits. We aimed to explain the plant defense physiological processes in *M. laxa*-infected fruits by measuring brown rot incidence (BRI), lesion diameter (LD), fruit firmness (FF), lignin content (LC), total antioxidant capacity (TAC), total soluble phenol content (TSPC), and enzyme activities of PAL, POD and SOD (5). Results showed that the postharvest applications of MeJA and SA enhanced the plant defense system of apricot fruit against brown rot by reducing fungal growth (BRI, LD) and by improving

physical and antioxidant attributes (FF, LC, TAC and TSPC) and the activity of defense-related enzymes (PAL, POD and SOD) in apricot fruits during shelf-life storage conditions.

I/b/ii sodium-benzoate

The food preservation material sodium benzoate was tested in postharvest trials on two scab-resistant apple cultivars (‘Topaz’ and ‘Florina’) (6). Assessments were made on six fruit loss parameters: percentages of healthy fruits, postharvest fruit rot, fruits with mechanical injury, fruits with russeting, damage by codling moth, and calcium (Ca) deficiency. These parameters were evaluated at three storage periods (1, 2, and 3 months after storage). Results showed that sodium benzoate (0.02%) significantly reduced postharvest fruit rot compared to water-treated fruit. This effect was observed at all three assessment dates and in both scab-resistant cultivars. Effects on other parameters varied among cultivars and assessment dates.

II) Study of the emergence and the progression of diseases appear jointly and the detailed investigation of major epidemiological interactions

In this work package, we focused on fungal diseases that appear jointly by investigating their characteristics under various pre- and postharvest conditions. We then attempted to generalize some of our disease epidemiology results by developing a tool to measure class-level accuracies.

II/a) Preharvest investigations on disease epidemiology: scab and powdery mildew in apple fruit development stages

In this task, we analyzed the joint distribution of the two diseases during the growing season, their interactions with other tree parameters, and how this knowledge can be useful in seasonal disease management. In an apple orchard, the joint developments of scab and powdery mildew were monitored over a 7-year study under four fertilization treatments (NP, NPK, NPKMg, and control) on a scab-susceptible cultivar (‘Golden Reinders’) and a scab- and mildew-tolerant cultivar (‘Pinova’) (7). Results showed that both cultivars and fertilizer treatments significantly influenced joint disease development. In most years, the NPKMg treatment provided the lowest disease incidences and the least damage from the joint disease appearance. Intercorrelations were also determined between scab and powdery mildew incidences and fruit parameters. Fruit size and weight exhibited a significant positive correlation with fruit scab incidence, which aligns with practical experience, as scabbed fruits tend to be smaller in size and weight compared to healthy fruits. Overall, fertilizer combinations demonstrated significant potential for inclusion in integrated disease management approaches to successfully reduce scab and powdery mildew development under Central European continental climate conditions.

II/b) Postharvest investigations on fruit decay disease complex in sour cherry

As sour cherry rapidly loses fruit quality after harvest, effective storage options are essential to minimize postharvest fruit decay disease complex. In our storage experiment, we measured fruit decay disease complex on sour cherry to better understand its interactions with cultivar susceptibility, storage conditions, and production systems, and how these interactions can aid postharvest disease management. Therefore, the fruit decay disease complex was investigated under two storage methods (normal atmospheric conditions and modified atmosphere packaging-MAP) on three cultivars (‘Érdi bőtermő,’ ‘Újfehértói fürtös,’ and ‘Petri’) and in three production systems (conventional, integrated pest management (IPM), and reduced IPM) following cold storage and shelf-life storage conditions (8). Results showed

that both normal atmospheric and MAP storage significantly reduced the fruit decay disease complex during cold storage, but fruit decay rapidly increased during shelf-life. Over the 14-day shelf-life period, major losses occurred from day 6 onward. Comparing the production systems, the incidence of decay disease complex followed the order: conventional < IPM < reduced IPM, with significant differences between the conventional and reduced IPM systems. Overall, results suggest that sour cherries produced under conventional or IPM systems and stored in modified atmosphere packaging can serve as an effective postharvest disease management strategy to significantly reduce postharvest fruit decay disease complex in sour cherry.

II/c) Generalization of disease epidemiology results: a tool to measure class level accuracies

Mathematical analyses of our multi-year epidemiological datasets were conducted to generalize model stability and accuracy at the class level (9). Accuracy assessments are critical steps in classification and have gained increasing relevance with the rise of machine and deep learning techniques. We developed a method for quick model evaluations with two options: i) calculating the class-level accuracy metrics for as many models and classes as needed; and ii) calculating model stability using random subsets of the testing data. Using our developed method, we demonstrated the stability of models and the accuracies of three experiments, including cherry leaf spot epidemiology data on 12 sweet cherry cultivars. We found that some popular metrics - binary Overall Accuracy, Sensitivity, Precision, Specificity, and the ROC (Receiver Operating Characteristic) curve - can produce misleading results when true negative cases dominate. In contrast, F1-score, Intersection over Union, and the Matthews correlation coefficient proved reliable in all experiments. Overall we found that a multi-metric evaluation is suggested instead of using a single metric.

III) Disease interactions under mixed cultivar planting systems

In this work package, we focused on the established knowledge that mixed cultivar planting systems (MCPS) reduce disease spread in the field and, therefore, delay the occurrence of disease epidemics. This can result in reduced fungicide use and, overall, a decrease in fungicide resistance. Consequently, MCPS has the potential to improve disease management strategies.

III/a) Investigation on sweet cherry

Cherry leaf spot (CLS, *Blumeriella jaapii*) causes significant epidemics in late summer and autumn in most cherry orchards, as crop protection is less intensive after harvest. In an MCPS design, we evaluated 12 mixed-planted sweet cherry cultivars under two training systems (4 × 1 m versus 5 × 2 m) to determine their effectiveness in delaying CLS epidemics and tree defoliation in an integrated orchard (10) in order to evaluate their ability to incorporate them into IPM strategies. Our results showed that the training system had a reducing effect on CLS epidemics. Annual CLS and defoliation incidences of individual cultivars were lower in trees planted at higher density (4 × 1 m) compared to those planted at lower density (5 × 2 m). This was attributed to increased light penetration and air movement within the tree canopy in the higher-density orchard. Our study also indicated that more severe CLS epidemics can be expected on older trees (13–15 years) compared to younger ones (4–6 years). However, these effects were significantly influenced by the number of infection periods and the CLS susceptibility of the cultivars. To address this, we developed a CLS cultivar classification scheme that combines infection periods and CLS incidence. Overall, our results demonstrated that training systems and tree age are practically useful factors in IPM strategies in years with

fewer than 10 CLS infection periods and for sweet cherry genotypes categorized as having low to moderate CLS susceptibility.

III/b) Investigation on plum

Most plum orchards, due to economic reasons, are treated less effectively against pests and diseases compared to high-density IPM apple orchards. Consequently, the effects of mixed cultivar planting and orchard training systems in delaying disease development could be crucial in mitigating epidemics of shot hole disease (SHD, *Stigmina carpophila*) in plum orchards. In our 3-year study, the temporal dynamics of SHD progression were analyzed under four training systems (4 x 1.5 m, 4 x 2 m, 5 x 2.5 m, and 6 x 3 m) and in combination with four plum cultivars ('Cacanska lepotica', 'Bluefre', 'Stanley', and 'President') exhibiting varying susceptibility to SHD. The aim was to identify time periods during which the combination of training systems and cultivars could effectively reduce SHD development (11,12). Results indicated that SHD incidence and the area under the disease progress curve (AUDPC) were significantly influenced by the combination of training systems and cultivars. The low-density training system (4 x 1.5 m) significantly reduced AUDPC and SHD incidence for three cultivars ('Cacanska lepotica', 'Stanley', and 'President') in September, October, and November compared to the high-density training system (6 x 3 m). These findings suggest that an appropriate combination of training system and cultivar can be effectively utilized to reduce SHD development as part of an integrated disease management approach during the establishment of new plantations.

III/c) Investigation on apple

As we observed two successful results for MCPS in delaying disease progression (IIIa and IIIb), we were curious to explore whether MCPS has any effect on apple fungal diseases in a well-treated IPM apple orchard. In this study, nine newly bred apple cultivars/mutants ('Jugala', 'Galaval', 'Gala Venus Fengal', 'Gala Decarli-Fendeca', 'Gala Schnitzer-Schniga', 'Fuji September Wonder', 'Crimson Crisp', 'Jeromine', and 'Red Idared') were investigated under MCPS across two planting densities. The aim was to determine whether MCPS interacts with the development of apple scab and powdery mildew, as well as with tree generative and vegetative parameters, including trunk cross-sectional area (TCSA), tree height (TH), tree yield (TY), fruit number per tree (FNT), crop load (CL), fruit diameter (FD), shape index (SI), fruit surface color (FSC), and fruit color intensity (FCI) (13). Correlation and regression analyses revealed significant interactions between vegetative and generative parameters. Principal component analyses demonstrated strong correlations for TCSA, TH, TY, and FNT in PC1; FNT, CL, and FS in PC2; and FSC and FCI in PC3. However, the study clearly showed that MCPS had no effect on the development of apple scab or powdery mildew, whether individually or jointly, in a well-treated IPM orchard. Disease incidences remained very low (below 3% for both diseases), attributed to the overall effective integrated disease management.

IV) Development of disease warning models and environmentally friendly disease management strategies based on organ specific disease interactions and improved MCPS

In this work package, the main aim was to develop new disease warning models and/or environmentally friendly disease management strategies: i) we set disease threshold levels for cherry leaf spot (*Blumeriella jaapii*); ii) we tested novel plant-disease detection approaches and deep learning-based data training, incorporating them into newly developed disease management strategies for jointly appearing pests in environmentally benign production

systems; and iii) we determined the biological, environmental, and economic benefits of certain disease management strategies in environmentally benign production systems under pre- and postharvest conditions.

IV/a) Disease threshold and disease warning models for cherry leaf spot

We established a 10% disease threshold value for cherry leaf spot (*Blumeriella jaapii*) as a possible disease warning model and evaluated whether commercial sweet cherry cultivars could meet this threshold requirement under two training systems (4 x 1 m and 5 x 2 m) (14). Results showed that the 10% threshold value was influenced by the training system in most cultivars. Among the 23 evaluated cultivars, 13 exhibited less than 10% infection under the 4 x 1 m spacing, while only 3 cultivars met this threshold under the 5 x 2 m spacing, reaching the 10% disease threshold value.

IV/b) Testing novel plant-disease detection approaches and deep learning-based data training, and their involvement in newly developed disease management strategies for jointly appearing pests in environmentally benign production systems

As part of pre-experiments for developing disease warning models, we tested novel modelling approaches, including deep learning-based data training. Specifically, we assessed i) the efficacy of machine learning and novel modelling approaches using UAV-based multispectral and thermal cameras (15) and ii) the efficacy of deep learning-based training data augmentation combined with post-classification for tree species prediction (16). These methods were subsequently adopted for experimental studies on fruit disease development. Parts of these techniques were incorporated into the development of new disease management strategies, specifically for managing brown rot and codling moth in sustainable apple production systems (17). While brown rot and codling moth damage are known to occur jointly in apple production, they had not been previously studied together for improving IPM. In a 12-year study, 27 apple cultivars (9 scab-resistant, 9 commercial, and 9 old) were assessed for their responses to brown rot in relation to codling moth damage under integrated and organic production systems. Cultivars were classified into three categories (“low,” “medium,” and “high”) based on season-long incidences of brown rot and codling moth damage. The 12-year temporal progression of brown rot and codling moth damage in each classification category was analyzed using novel modelling approaches. Five model variables were derived for brown rot and codling moth damage, and intercorrelations were demonstrated between brown rot and codling moth damage in relation to model derivatives and cultivar classification categories. These insights were used to differentiate cultivar responses to brown rot and codling moth damage. Based on the derived model variables and classification relationships, a new brown rot and codling moth forecasting and management strategy (BRCM-FMS) was developed. BRCM-FMS was compared with a general pest management program (GPMP) in an additional 4-year study. This study demonstrated that the BRCM-FMS reduced annual spray applications by 21.4–41.7% in integrated and 12.5–31.3% in organic production systems compared to GPMP. Despite the reduced spray numbers, disease incidences in the two programs remained similar across all years, production systems, and classification categories. Fewer spray applications with comparable disease incidences provided significant economic and environmental benefits for both integrated and organic growers.

IV/c) The suitability of non-chemical control strategies for IPM systems: biological, environmental, and economic benefits of certain disease management strategies in environmentally benign production systems under pre- and postharvest conditions

IV/c/i) Reduced fungicide use lowers environmental pollution and enables safer food production. Fungicide usage in apple orchards can be minimized through the application of sanitation practices that reduce inoculum sources of apple scab disease on fallen leaves. In a 5-year preharvest trial, we aimed to determine the potential biological and economic benefits of apple scab sanitation practices (lime sulfur, leaf collection, mulching, lime sulfur + leaf collection, leaf collection + mulching) in integrated and organic apple management systems at harvest (18). Results showed that treatments involving leaf collection and/or leaf collection + mulching resulted in lower scab incidence, higher yield, and greater total revenues and income surpluses compared to non-sanitized control treatments in most cases for both integrated and organic orchards. Other sanitation treatments provided fewer biological benefits and/or no financial benefits. In conclusion, our study demonstrated that leaf collection and leaf collection + mulching are not only biologically and environmentally valuable, as they reduce disease levels and can replace chemical fungicides, but they are also economically efficient options for integrated and organic orchards compared to non-sanitized ones.

IV/c/ii) While evaluating the economic benefits of orchard sanitation practices against apple scab, we addressed another practical question: does this benefit persist after fruit storage in the high-energy-consuming ultra-low oxygen (ULO) storage system? Consequently, our investigations on the biological and economic benefits of sanitation practices in integrated and organic apple productions were extended to postharvest conditions after 6 months of ULO storage (19). Our results revealed that ULO storage costs were twice as high in the integrated orchard as in the organic one. Direct costs of the two combined sanitation treatments (lime sulfur + leaf collection, leaf collection + mulching) were significantly higher than those of lime sulfur or leaf collection treatments across all years and orchard systems. Total revenue and revenue for class 1 fruit were significantly higher in the integrated orchard than in the organic orchard. The lowest total revenue was observed in the non-sanitized control, whereas the highest revenue was recorded in the leaf collection or leaf collection + mulching treatments. These treatments also provided the highest income surplus across all years and orchard systems. In conclusion, our study demonstrates that leaf collection and leaf collection + mulching treatments offer the greatest economic benefits after 6 months of ULO storage, regardless of the orchard system employed.

Our 25 years of research results have received recognition from Burleigh Dodds Science Publishing (Cambridge, UK), leading to an invitation to contribute a book chapter titled “Brown rot: causes, detection and control of *Monilinia* spp. affecting tree fruit” in the book “Integrated management of diseases and insect pests of tree fruit” (20). Additionally, the American Phytopathological Society (APS) invited us to write three short book chapters on “Cercospora leaf spot (*Cercospora circumscissa*)”, “Gnomoniosis (*Apiognomonia erythrostoma*)”, and “Red leaf spot (*Polystigma rubrum*)” for the “Compendium of stone fruit diseases” (APS). These chapters were submitted to the editors in January 2024 and are scheduled for publication by APS in 2025.

V) Research paper publications in relation to this project and listed in NKFIH-OTKA web-page

1) Ezzat, A., El-Sherif, A. R., Elgear, D., Szabo, S., Holb, I.J. 2020. A comparison of fruit and leaf parameters of apple in three orchard training systems. **ZEMDIRBYSTE-AGRICULTURE** 107(4): 373-382.; **Q2**

2) Orosz-Tóth, M., Nemes-Kun, A., Lowy, D. A., Csihon, A., Sándor, Z., Kincses, I., Holb, I.J. 2022. Comparison and intercorrelation of extraction methods for polyphenol content and antioxidant capacity of scab-resistant apple cultivars. **AGRONOMY** 12 (2): 289.; **Q1**
3) Salama, A.M., Ezzat, A., El-Ramady, H., Alam-Eldein, S.M., Okba, S., Elmenofy, H.M., Hassan, I.F., Illés, A., Holb, I.J. 2021. Temperate fruit trees under climate change: challenges for dormancy and chilling requirements in warm winter regions. **HORTICULTURAE** 7(4): 86.; **Q1**
4) Ezzat, A., Hegedűs, A., Szabó, Sz., Ammar, A., Szabó, Z., Nyéki, J., Molnár, B., Holb, I.J. 2020. Temporal changes and correlations between quality loss parameters, antioxidant properties and enzyme activities in apricot fruit treated with methyl jasmonate and salicylic acid during cold storage and shelf-life. **APPLIED SCIENCES** 10 (22), 8071.; **Q1**
5) Ezzat, A., Szabó, S., Szabó, Z., Hegedűs, A., Berényi, D., Holb, I.J. 2021. Temporal patterns and inter-correlations among physical and antioxidant attributes and enzyme activities of apricot fruit inoculated with *Monilinia laxa* under salicylic acid and methyl jasmonate treatments under shelf-life conditions. **JOURNAL OF FUNGI** 7(5): 341.; **Q1**
6) Molnár, B., Szabó, S., Veres, Á., Holb, I.J. 2020. Effect of postharvest sodium benzoate treatment on some fruit parameters of two organic apple cultivars. **INTERNATIONAL JOURNAL OF HORTICULTURAL SCIENCE** 26: 35-37.
7) Csihon, Á., Gonda, I., Sipos, M., Holb, I.J. 2024 Impacts of N-P-K-Mg fertilizer combinations on tree parameters and fungal disease incidences in apple cultivars with varying disease susceptibility. **PLANTS** 13: 1217.; **Q1**
8) Sándor, E., Mihály, K., Nagy, A., Pál, K., Peles, F., Zabiák, A., Kovács, C., Takács, F., Romanazzi, G., Holb, I.J. 2024. Effects of storage conditions, cultivars, and production systems on fruit decay incidence of sour cherry (*Prunus cerasus* l.) fruit after shelf-life conditions. **AGRONOMY** 14, 2212. **Q1**
9) Szabo, Sz., Holb, I.J., Abriha-Molnár, V.É., Szatmári, G., Singh, S.K., Abriha, D. 2024. Classification Assessment Tool: A program to measure the uncertainty of classification models in terms of class-level metrics. **APPLIED SOFT COMPUTING JOURNAL** 155: 111468.; **Q1**
10) Vámos, A., Holb, I.J. 2019. Training system and tree-age affect leaf spot epidemics and tree defoliation on commercial sweet cherry cultivars. **CROP PROTECTION** 125: 104881.; **Q1**
11) Molnár, B., Szabó, S., Holb, I.J. 2022. Temporal dynamics of incidence of shot hole disease affected by training systems and cultivar susceptibilities in an integrated plum orchard. **JOURNAL OF FUNGI** 8 (6): 580; **Q1**
12) Molnár, B., Holb, I.J. 2023. Effect of training system on the incidence of *Stigmina carpophila* and fruit size and weight of European plum (*Prunus domestica*). **INTERNATIONAL JOURNAL OF HORTICULTURAL SCIENCE** 29: 78-80.
13) Csihon, A., Gonda, I., Szabó, S., Holb, I.J. 2022. Tree vegetative and generative properties and their inter-correlations for prospective apple cultivars under two training systems for young trees. **HORTICULTURE, ENVIRONMENT, AND BIOTECHNOLOGY** 63: 325-339.; **Q1**
14) Varga, M., Vámos, A., Molnár, B., Holb, I.J. 2019. Disease threshold for cherry leaf spot incidence on commercial sweet cherry cultivars. **INTERNATIONAL JOURNAL OF HORTICULTURAL SCIENCE** 25(1-2): 52-54.
15) Bertalan, L., Holb, I.J., Pataki, A., Szabó, G., Szalóki, A. K., Szabó, Sz. 2022. UAV-based multispectral and thermal cameras to predict soil water content–A machine learning approach. **COMPUTERS AND ELECTRONICS IN AGRICULTURE** 200: 107262.; **D1**

16) Likó, S.B., Holb, I.J., Oláh, V., Burai, P., Szabó, Sz. 2024. Deep learning-based training data augmentation combined with post-classification improves the classification accuracy for dominant and scattered invasive forest tree species. **REMOTE SENSING IN ECOLOGY AND CONSERVATION** 10 (2): 203-219. (corresponding author: I.J. Holb); **D1**
17) Holb, I.J., Dremák, P., Barkaszi, I., Abonyi, F., Lakatos, P., Gáll, J.M., Vasileiadis, V.P., Gonda, I. 2022. Developing a management strategy based on the relationships between brown rot and codling moth in two apple production systems. **AGRONOMY FOR SUSTAINABLE DEVELOPMENT** 42 (2): 30.; IF: 7.832 (**D1**)
18) Antal, G., Szabó, Sz., Szarvas, P., Holb, I.J. 2024. Yield and cost–benefit analyses for apple scab sanitation practices in integrated and organic apple management systems. **PLANTS, PEOPLE, PLANET** 6(2): 470-489.; **D1**
19) Antal, G., Szabó, Sz., Szarvas, P., Pusztahelyi, T., Gáll, J.M., Holb, I.J. 2024. Cost-benefit analysis of apple scab sanitation practices for ulo stored apple fruit in integrated and organic production systems. **INTERNATIONAL JOURNAL OF FRUIT SCIENCE** 24 (1): 332-348.; **Q1**
20) Holb I.J. 2019. Brown rot: causes, detection and control of *Monilinia* spp. affecting tree fruit. Integrated management of diseases and insect pests of tree fruit. Cambridge, UK: Burleigh Dodds Science Publishing 103-150.

VI) Some additional publications in Q1-D1 journals throughout the project duration

These publications were only partially or NOT related to this specific NKFIH K131478 project but they show a wider scale of research (publication) activity of the principal investigator. Therefore, these papers were NOT GIVEN to publication lists of the NKFIH-OTKA web-page:

- Ezzat, A., Salama, A. M., Szabó, S., Yaseen, A. A., Molnár, B., Holb, I.J. 2021. Deficit irrigation strategies on tree physiological and chemical properties: treatment effects, prediction based model analyses and inter-correlations. **AGRONOMY** 11(7): 1361.; **Q1**
- Karányi, Z., Mosolygó-L, Á., Feró, O., Horváth, A. Boros-Oláh, B., Nagy, É., Hetey, Sz., Holb, I.J., Szaker, H.M., Miskei, M., Csorba, T., Székvölgyi L. 2022. NODULIN HOMEOBOX is required for heterochromatin homeostasis in Arabidopsis. **NATURE COMMUNICATIONS** 13 (1), 5058.; IF: 17.694 (**D1**)
- Likó, S.B., Bekő, L., Burai, P., Holb, I.J., Szabó, Sz. 2022. Tree species composition mapping with dimension reduction and post-classification using very high-resolution hyperspectral imaging. **SCIENTIFIC REPORTS** 12: 20919. (corresponding author IJ Holb); **D1**
- Négyesi, G., Szabó, S., Buró, B., Mohammed, S., Lóki, J., Rajkai, K., Holb, I.J. 2021. Influence of soil moisture and crust formation on soil evaporation rate: A wind tunnel experiment in Hungary. **AGRONOMY** 11(5): 935.; **Q1**
- Phinzi, K., Holb, I.J., Szabó, S. 2021. Mapping permanent gullies in an agricultural area using satellite images: efficacy of machine learning algorithms. **AGRONOMY** 11: 333. (corresponding author IJ Holb); **Q1**
- Rakonczás, N., Kállai, Z., Kovács, B., Antal, G., Szabó, S., Holb, I.J. 2023. Comparison and intercorrelation of various bentonite products for oenological properties, elemental compositions, volatile compounds and organoleptic attributes of white wine. **FOODS** 12(2): 355.; **Q1**
- Varga, O.G., Kovács, Z., Bekő, L., Burai, P., Csatáriné Szabó, Z., Holb, I.J., ... & Szabó, S. 2021. Validation of visually interpreted Corine Land Cover classes with spectral values of satellite images and machine learning. **REMOTE SENSING** 13(5): 857.; **Q1**