SZENT ISTVÁN EGYETEM

BIOLOGICAL DIVERSITY AND FUNGICIDE SENSITIVITY OF *MONILINIA* SPECIES IN HUNGARY

Thesis of PhD dissertation

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1. INTRODUCTION

Monilinia disease is one of the most significant parts of plant protection on stone and pome fruit all over the world. Blossom blight and brown rot attended by the infection endanger the crops during vegetation period. Cancers emerged followed by the spreading of the infection, which causes the impairment of the tree's condition and collectively with other factors can inflict the necrosis of the tree. Up to now, five *Monilinia* species have been observed in Hungarian orchards, two of them had been first reported in the last 10 years.

Understanding the occurrence of various species and populations is relevant, because the presence of the species impacts the control measure strategies. Studying the biology, symptoms and life cycle of the recently appeared species is as important, as monitoring the fungicide sensitivity of the native species. Evidence of populations with reduced fungicide sensitivity was published before but resistant isolates have not been detected in Hungary.

Monilinia laxa and *Monilinia fructigena* are indigenous pathogens in Europe, control measure strategies are established. In the last years despite consequent fungicide sprays brown rot blossom blight causes frequent epidemics in several regions of Hungary. According to Rozsnyai and Vajna (2001) more aggressive pathotypes or strains of *Monilinia laxa* appeared at the beginning of the 20th century. The epidemics expand on apricot and sour cherry orchards, in addition to some of the almond, plum and peach cultivars. Beside the widening of the susceptive hostplants, the fungicide sensitivity of the subpopulations is also changing. In the last years studies on Hungarian *Monilinia laxa* and *Monilinia fructigena* subpopulations showed reduced sensitivity for site-specific fungicides (Sződi *et al.* 2008, Fazekas 2014).

Monilinia linhartiana is the specific pathogen of quince, native in Hungary. The pathogen was first described by a Hungarian botanist and mycologist György Linhart, and the nomenclature commemorates his name. In Hungary, the symptoms of the disease had been observed since the 1930s (Glits 2000), although the pathogen has rarely appeared in recent decades. The steadily increasing area of quince orchards in Hungary adumbrates the spreading of the fungus causing remarkable loss, as it happened in the Mediterranean region, where losses of 90- 95 % were reported.

In 2005 *Monilinia fructicola* was reported from imported peaches (Petróczy and Palkovics 2006), while in 2007 the presence of the pathogen was confirmed in Hungarian orchards (Kiss 2007). In the last decades the pathogen spreaded all over Europe, therefore the pathogen was deleted from the list of EU quarantine pests (Plant 2014). In Hungary the

prevalence of the pathogen has not been studied. The widespread of the pathogen will modify control measures and technology since the use of fungicides becomes necessary during the ripening season. In Italy, Spain and Greece fungicide sprays are necessary before harvest for the protection of the ripening fruits (Ogawa *et al.* 1995).

Monilinia polystroma caused blossom blight in apple orchards of Újfehértó in 2008 (Petróczy and Palkovics 2009). It was the only case when the presence of the pathogen was reported from Hungary. Nowadays the pathogen was isolated in several countries of Europe from stone and pome fruit orchards. An Italian survey found that *M. polystroma* is the most frequent pathogen on pome fruits out of *Monilinia* spp. (Martini et al. 2014).

Research on *Monilinia* disease are relevant from more aspects. The understanding of the dominancy of *Monilinia* species is indispensable sithence they influence the plant protection strategies on fields. Nowadays the importance of the species are changing in Europe. The spreading of *Monilinia fructicola* and *Monilinia polystroma* implies the widening of the hostplants, the sensitivity of the cultivars, modifies the symptoms and the control measure strategies.

To follow the changes of the native species' populations is also necessary. On stone fruit orchards fungicide sprays are required in the spring time, thus the uphold of the efficacy of the pesticides is highly important. Previous studies found subpopulations with reduced sensitivity but not resistance. In our work we continue the monitoring work intending for functional and effective technologies.

Our main goals were the following:

- Estimate the dominancy of *Monilinia* species involving several regions of Hungary,
- Observe the symptoms of the disease and collecting samples,
- Identification of the samples along morphological signs and molecular methods,
- Studying characteristic regions of the genome (ITS region, β-tubulin gene, 14 α-demethylase gene) for better understanding the phylogenetic relations,
- Testing the fungicide sensitivity of the pathogens *in vitro*,
- Analyze the molecular background of resistance.

2. MATERIALS AND METHODS

Dominancy of *Monilinia* species

To evaluate the dominancy of the species samples were collected from all fruit producer regions of Hungary. Infected shoots and fruits originated from orchards using integrated pest management and from trees where fungicides were not applied. From one location 1-5 infected shoots or fruits were sampled. The pathogens were isolated on potato agar plates and they were identified by classical mycological and molecular methods. In Érd-Elvira major, Sóskút and Soroksár the flower infection of *Monilinia fructicola* were monitored carefully. The results of the 3 years were factored by year, host plants, regions and fungicide usage.

Isolation

Shoots and fruits showing typical symptoms of *Monilinia* disease were collected from different parts of Hungary: orchards, gardens, public places between 2013-2015. Under stereomicroscope the infected parts were observed and spores were places onto potato dextrose agar (PDA) plates. After 3 days colonies were transferred onto fresh agar plates one by one and the pathogenicity was tested. Isolates were stored in fridge on 4°C and replaced every 2 month.

Morphological and cultural characteristics

The colour, size and berth of stromata, the structure of the conidial chains and the morphology of the conidia were observed. 100-100 conidia and 20-20 disjunctors of the *Monilinia linhartiana* isolates were measured.

The cultural signs were observed on potato dextrose plates: the color, structure, shape, margins, patterns, growth rate (mm/day) and production of aerial mycelium or conidia. In case of *Monilinia linhartiana* isolates attributes were determined also on Leonian malt agar and malt extract agar culture media.

Fungicide sensitivity tested *in vitro*

Fungicide sensitivity was tested on amended agar plate method. Efficacy of 7 active ingredients were tested on all isolates collected in 2013-2014, further 15 active ingredients or combinations were tested on *Monilinia linhartiana* isolates.

Discriminatory dose was added to the PDA plates of the following active ingredients: boscalid (Spiegel and Strammler 2006), pyraclostrobin (Chen *et al.* 2013), thiophanate-methyl

(Ma *et al.* 2003, 2005) and tebuconazole (May-De Mio *et al.* 2011). Field dose and its ten-fold dilution were tested in case of ciprodinil, fenhexamid, penconazole and the fungicides against *Monilinia linhartiana*. The experiment was repeated in three replicates. Results were determined when the mycelium of the controls overgrew the Petri dish. Growth was measured in two perpendicular directions and growth rate (%) was calculated (May-De Mio *et al.* 2011).

Molecular biology methods

The DNA was extracted by CTAB (cetyltrimethylammonium bromide) method (Maniatis *et al.* 1989) followed by chloroform and isoamyl alcohol (24:1) extraction (Gell *et al.* 2007). Different parts of the genome were multiplied by polymerase chain reaction. For the ITS region ITS5 and NL4 primers were used (White *et al.* 1990, Kurtzman and Robnett 1997), for the molecular identification Unimon primer pair (Petróczy *et al.* 2012), for the14α-demethylase enzyme gene 3 pairs of primers, published in Luo and Schnabel (2008). For the cytochrome gene and the β-tubulin gene new primers were designed.

The products of the PCR were checked in 1% agarose gel and purified with PCR High Purification Kit (Roche, Germany) according to the manufacturer's protocol. Final DNA concentrations were verified by spectrophotometry (NanoDrop 2000). Fragments were sequenced in three replicates in an ABI Prism automatic sequencer (BaseClear B.V., Leiden, The Netherlands).

Nucleotide sequence identities were determined by BLAST analyses (Altschul *et al.* 1999). Multiple alignments were performed by using the MAFFT 7 software, L-INS-i method. Phylogenetic analyses was calculated with BEAST v2.3.2 (Drummond *et al.* 2012). Interspecific and intraspecific diversities were calculated by the CLUSTAL O (1.2.1) multiple sequence alignment program (Sievers *et al.* 2011).

Molecular background of the resistances

In fungicide resistance assays were followed by the analysis of the molecular background of benzimidazole, triazole and strobilurin resistance. Isolates were selected on the strength of their sensitivity showed on amended medium. Sensitive and resistant isolates were selected in case of each active ingredient. Changes of the *tub2*, *cyp51* and *cybt* genes were analyzed looking for mutation in the active site which induces the reduced efficacy, particularly the alleles where mutation was detected previously.

3. RESULTS AND DISCUSSION

Dominancy of *Monilinia* species

Monilinia species were isolated 556 times from stone fruit hosts and occasionally from pome fruit hosts. *Monilinia laxa* was the most frequent species on stone fruit hosts. From the shoots and flowers exclusively this species was identified. *Monilinia fructicola* can also cause flower infection. In our study we could not isolate the pathogen from flower probably because the climate is cold in the spring time (Kimura 1962, Harada 1977), but it may change as winters become milder or spring temperature rises.

Monilinia laxa causes approx. half of the fruit rots, while *Monilinia fructigena* and *Monilinia fructicola* cause 15-30% of the fruit rots each year. *Monilinia polystroma* was detected sporadically. *Monilinia polystroma* was isolated for the first time from mature apple and plum fruits in Hungary. Considering previous results from other European countries (Poniatowska *et al.* 2013, De Cal *et al.* 2014, Martini *et al.* 2014, Papavasileiou *et al.* 2015), we expect increased future significance of *Monilinia fructicola* and *Monilinia polystroma*. *Monilinia linhartiana* was isolated four times from quince shoots in Hungary.

Identification of *Monilinia* species

The color and size of the exogenous stromata of *Monilinia laxa* are highly similar to *Monilinia fructicola*, and *Monilinia fructigena* to *Monilinia polystroma* (van Leeuwen *et al.* 2002). Along these characters we could not separate the species reliably. *M. linhartiana* does not have exogenous stromata, the conidia chains develop on the surface of the leaves. Conidia chains of *Monilinia linhartiana* are also different from the chains of the group of *Junctoriae* (Woronin 1888). Under stereomicroscope disjunctors were observed and characterized.

Cultural signs of *Monilinia laxa*, *Monilinia fructigena* and *Monilinia fructicola* meet with the observation of previous studies (Byrde and Willetts 1977, Barta 1991, OEPP/EPPO 2009). Our *Monilinia polystroma* isolates showed similar signs to the Japanese isolates of Leeuwen *et al.* (2002). There are only a few descriptions of the cultural sign of *Monilinia linhartiana* (Berkhout 1923, Moral *et al.* 2011), the attributes were similar to these observations but all of our isolates brown, stroma-like formations appeared around the inoculation point, which has not been mentioned in other studies.

The multiplex PCR based molecular identification (Petróczy *et al.* 2012) worked reliably, multiplied the specific length of each species: from *Monilinia laxa* 341 bp, from

Monilinia fructigena 360 bp, from *Monilinia fructicola* 537 bp and from *Monilinia polystroma* 476 bp. Polymorphic region of *Monilinia linhartiana* was sequenced for the first time, all 4 isolates contained 342 bp between the primers.

Fungicide sensitivity of *Monilinia* species

Fenhexamid and penconazole showed excellent fungicide effect in both dilutions. Ciprodinil blocked *M. fructicola* and *M. linhartiana* isolates, but not all *M. laxa, M. fructigena* and *M. polystroma* isolates. Boscalid could not inhibit the growth of any *Monilinia* isolate, the average inhibition of species did not reach even 40%.

19% of *M. fructicola*, 22% of *M. laxa*, 2 of the *M. linhartiana,* and 1-1 of the *M. polystroma* and *M. fructigena* isolates showed low resistance to thiophanate-methyl. Sixty-nine percent of *M. fructicola* isolates showed high resistance to thiophanate-methyl. The E198A point mutation in the beta-tubulin gene was first reported from Hungary by us in case of highly resistant *M. fructicola* isolates. Other point mutations, which could also result in low resistance were not present in this gene. We assume that low resistance caused by changes in beta-tubulin gene is probably located in the second part of the gene which we did not study.

Forty-four percent of *M. laxa* isolates, 50% of *M. fructicola* isolates and all of the *M. fructigena* isolates were able to grow on pyraclostrobin-containing plates. In previous studies we also found *M. laxa* isolates with reduced sensitivity to azoxystrobin. Generally, strobilurin resistance is caused by mutations in the cytochrome b gene, but we could not detect any of the F129L, G137R or G143A mutations (Luo és mtsai. 2010, Miessner és Stammler 2010).

Sixty-five percent of *M. laxa*, 46% of *M. fructigena*, 38% of *M. fructicola* isolates and 2 of the *M. linhartiana* and 1 of the *M. polystroma* isolates showed reduced sensitivity to tebuconazole. Neither the promoter region nor the full sequence of the α-demethylase gene contained any variations, which could be responsible for reduced sensitivity. Unlike in the American populations the mutation does not appear in this gene, but more likely in the ABC transporter genes.

We recommend the application of the following pesticides against *Monilinia linhartiana* pathogen: boscalid+piraklostrobin, iprodione, captan, miklobutanil, prochloraz, propineb, tebuconazole+trifloxystrobin. The efficacy of the copper-containing fungicides was greatly reduced in 10 times dilution, inhibition did not exceed 20% in average, this is why special attention is needed to choose an efficient dose and to reach a complete spray coverage.

In the future farmers may face new difficulties. The changing of the dominancy, the appearance of the flower infection of *Monilinia fructicola*, evolution or import of resistant

subpopulations infer the modification of plant protection. After North-America (Amiri *et al.* 2010, Chen *et al.* 2013) multiresistant populations appeared also in Europe (Egüen *et al.* 2016). In our study *Monilinia* species were mostly sensitive or low resistance to the fungicides, only *Monilinia fructicola* subpopulations were highly resistant to thiophanate-methyl. Currently benzimidazol resistant endanger the fruit crop production moderately in Hungary. Considered and consequent usage of the pesticides protect their efficacy for the next generations, ensuring quality and quantity of the convenient fruit production.

4. SUMMARY OF NEW SCIENTIFIC RESULTS

1. A comprehensive survey was performed to determine the dominancy of *Monilinia* species in Hungary. Correlated to previous results the increase of *Monilinia fructicola* was observed.
2. New symptom of *Monilinia laxa* was observed on apricot host. After the shoot growth was complete the pathogen infected and necrotized the shoots.
3. *Monilinia polystroma* have been reported for the first time from stone fruit hosts and from ripped apple fruits.
4. New data were published by the specific pathogen of quince. Morphology and fungicide sensitivity of *Monilinia linhartiana* was characterized for the first time in Hungary.
5. Resistance of *Monilinia* sp. was detected for the first time in Hungary. *Monilinia fructicola* is highly resistant to benzimidazoles, induced by the E198A mutation of the β-tubulin gene.
6. Beta-tubulin gene and 28S rDNA gene of *Monilinia linhartiana,* partial sequence of the beta-tubulin gene and 28S rDNA gene of *Monilinia polystroma,* the cyp51 gene of *Monilinia laxa, Monilinia fructigena, Monilinia polystroma, Monilinia linhartiana, a polimorf region of Monilinia linhartiana* were sequenced for the first time. First data of ITS region of Hungarian *Monilinia linhartiana* isolates were published as well.

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6. PUBLICATIONS

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