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The biotic adversities of poplar in Italy: a reasoned analysis of factors determining the current state and future perspectives

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Abstract - Poplar cultivation in Italy since its early stages has been conditioned and orientated by biotic and abiotic adversities. Spontaneous hybrids between European black poplar (*Populus nigra* L.) and Eastern cottonwood (*Populous deltoides* W. Bartram (Marshall) were empirically introduced into cultivation for their suitable characters of branchiness, rooting and tolerance to root rots; nevertheless, the first true scientific programme of genetic improvement began after leaf and shoot blight epidemics from Venturia populina during the second and third decades of the twentieth century. The resulting selection of resistant 'I-214' clone fostered poplar cultivation in Italy, but at the same time «crystallised» it in a condition of delay with respect to other European countries. With the arrival of leaf spot disease from Marssonina brunnea in the Sixties, phytoiatric treatments were introduced rather than diversifying with more resistant genotypes. Similarly, the increased virulence of leaf rusts from Melampsora spp. starting from about twenty years later, did not succeed in undermining the near monopolisation of 'I-214'. At present, Marssonina leaf spot and leaf rusts are the most incident diseases: fungicide treatments are carried out mainly on the plantation against the former and mainly in the nursery against the latter. The woolly aphid (*Phloeomyzus passerinii*) is the most constant and incident pest in plantations. Besides, persisting problems are associated with new pests mainly of exotic origin, especially with the brown marmorated stink bug (*Halyomorpha halys*).

Experiences in other important European poplar cultivation systems highlight the suitability of genetic control, together with a diversification of planted material and efficient agronomic practices. It is advisable to undertake research programmes for vertical and horizontal or quantitative (QTL) resistances, recurring to molecular markers, associated with studies on epigenetics and on microbial communities of various tissues through the new approach offered by metagenomics. The complexity of poplar agrosystems should be increased promoting a homeostatic control of pathogens and pests through antibiotic or competitive features triggered by other microbiota components.

Keywords - poplar pests; poplar diseases; disease management; pest management.

Introduction: a perspective on biotic adversities of poplar in time as a forging factor of the whole cultivation

Italian poplar cultivation, in a favourable period once again after many years of decline, is at a critical point of its history: for the first time several new clones, owing to their selected genetic characters, are available for ecologically sustainable cultivation and suitable for technological exploitation by final users (Agreement of Venice 2014). Among the goals of the Agreement there is a general enhancing and expansion of poplar cultivation owing to its productive and environmental value, and the award to cultivators of carbon credits corresponding to greenhouse gas stoking power. After persisting mistrust by farmers and rooted ostracism from wood industries versus clonal innovations, there are finally real opportunities to reduce the 'I-214' hegemony, still constituting 75% of plantations according to the latest Italian sector inventory, over Italian poplar supply chain; a hegemony that has repeatedly proved dangerous for agrosystem stability. To this diversifying trend, some recent legislative measures in the field of disease and pest management have also concurred, since the EC 128/2009 Directive on sustainable use of Plant Protection Products (PPPs) and the EC 1107/2009 Regulation, regarding the introduction in trading of PPPs, have induced a dramatic reduction of the spectrum of fungicides and insecticides available in poplar cultivation in a context of mandatory integrated pest management (Legislative Decree 150/2012). However, a sustainable management of plantations would have positive outputs in terms of regulating flood waters, stocking CO_2, building ecological networks and conserving biodiversity (Corona et al. 2018), whereas a traditional poplar cultivation is associated with considerable environmental costs, e.g. an almost double fresh water ecotoxicity, mainly due to fungicide treatments (Chiarabaglio unpublished data). Since conducing a 'I-214' plantation involves several fungicide treatments, the necessity for its progressive substitution is unavoidable.

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Owing to the high qualitative and quantitative standards of the modern poplar wood product, a bad tackling of the various biotic and abiotic adversities recurring during cultivation is indeed not suitable and would imply serious damage. The damage may consist of wood quality loss, induced by bark canker pathogens or by wood borers, or of wood quantity loss, induced by root rot and foliar pathogens or by defoliating and sucking pests. In addition, short-term rotation stands are especially subjected to regeneration damage connected with root rots and stump decay favoured by repeated cuts at the collar. Incidentally, it should be noted that the historically most important disease epidemics of poplar cultivation (Table 1), i.e. spring blight, rusts and Marssonina leaf spot, affect green tissues (leaves and shoots) and are associated with quantitative damage, whereas the historically most incident pests (Tab. 2) may induce quantitative damage [(*Cryptorhynchus lapathi* (L.), *Phloeomyzus passerinii* (Sign.)] or quality loss [*Saperda carcharias* (L.), *Cossus cossus* (L.)].

In this review, we aim at drawing a coherent and diachronic picture of the pathosystem and the infesting entomofauna associated with poplar cultivation in its history and at highlighting their role in the evolution of the same cultivation; some outlines for future research, and for advanced disease and pest management, are also given.

Traditional poplar cultivation in Italy as a result of the first dramatic fungal epidemics: the empirical selection era

It must be remembered that 'I-214' is in itself «son» of a disease. In fact, it was the lucky outcome of a careful but empirical selection performed by Jacometti in 1929 in Villafranca Sabauda (Turin, Piedmont) experimental station on genetic material derived from cultivated genotypes and ornamental individuals collected in Piedmont; this selection was specifically designed for resistance to spring leaf and shoot blight induced by *Venturia populina* (Vuill.) Fabric. (anamorph: *Pollaccia elegans* Servazzi), epidemics of which caused economic damage of about 60% over fifteen years during the second and third decades of the 20th century (Castellani and Prevosto 1970). *V. populina* attacks the new foliar and green tissues of the year and its outbreaks are enhanced by cold and wet spring weather, inducing large olive-coloured blotches on the leaf blade along the main veins and a quick browning and desiccation of the fresh shoots, which take on a typical hook shape (Fig. 1). The parasite took advantage of the high susceptibility of poplar populations present at that time in northern Italy, mostly composed of «Canadian» hybrids, of uncertain genetic composition but the exotic parent of which was conventionally referred to as *P. deltoides* Bartr. subsp. *monilifera* (Aiton) Eckenw., characterised by a dense and aggregated crown and thin twigs regularly distributed on the trunk that suggested a wood of good quality to cultivators.

Figure 1 - Poplar shoot infected by *Venturia populina* with the typical hook shape.

«Canadians» themselves were previously collected and exchanged, in the context of that embryonal poplar cultivation of the first twenty years of the century, indeed for their attracting characters, but not secondly for the presence among them of genotypes provided with a generic resistance to leaf rusts from *Melampsora* spp. and some diseases presently with no incidence, such as leaf blister by *Taphrina populina* Fr. or powdery mildew from *Erysiphe adunca* (Wallr.) Fr. Besides, «Canadians» as a group, in addition to having a better rooting after transplanting, were resistant or tolerant to dematophora root rot from *Rosellinia necatrix* Berl. ex Prill., an occasional parasite in poplar cultivations on marginal soils, but at that time very incident because of still rough agronomic management (Table 1). This was the main reason for their preferred use with respect to the so called «Carolinians», whose exotic parent was once ascribed to *P. deltoides* Bartr. subsp. *angulata* (Aiton) Sarg., roughly recognisable for their expanded crown, thick twigs irregularly distributed on the trunk and a heavier foliage. Even though more tolerant to water stress than «Canadians», «Carolinians» were more subjected to wind damage and their wood was considered to

Table 1 - Chronology of cultivated poplar diseases in Italy with basic features (qualitative incidence scale: 0 = no incidence, 1 = low, 2 = moderate, 3 = high, 4 = very high; the cited clones are only as examples).

Onset period of epidemics	Present incdence	Disease [pathogenic agent]	Susceptible clones	Control strategy
Until 1900	0	Leaf blister [*Taphrina populina* Fr.]	Old "Canadians"	-
Until 1900	0	Leaf powdery mildew [*Erysiphe adunca* (Wallr.) Fr.]	Old "Canadians"	-
Until 1900, then occasional	2	Dematophora root rot [*Rosellinia necatrix* Berl. ex Prill.]	Non-clonal susceptibility (at first "Carolinians")	Agronomic
Until 1900, then since 1980s	4	Leaf rusts [*Melampsora larici-populina* Kleb. pvv. E1 and E3, *M. allii-populina* Kleb.]	'L. Avanzo', 'Neva', 'Carpaccio', 'Bellini', 'Stella Ostigliese'	Genetic Chemical
1910s, 1930s, then occasional since 1980s	3	Dothichiza stem canker [*Chryptodiaporthe populea* (Sacc.) Butin]	'Bellini', 'Guardi', 'Jean Pourtet', 'Stella Ostigliese' (at first "Carolinians")	Agronomic Chemical
1920s-1930s, 1990s, then occasional	2	Spring leaf and shoot blight [*Venturia populina* (Vuill.) Fabric.]	"Canadians", 'Neva', 'Branagesi', 'Adige', 'Stella Ostigliese'	Genetic Agronomic
1950s, 1980s, then occasional	2	"Brown spots" physiologic disorder [-]	Surviving "Canadians", 'I-488', 'L. Avanzo', 'Jean Pourtet', 'Bellini'	Agronomic Genetic
Since 1960s	4	Marssonina leaf spot [*Drepanopeziza brunnea* (Ellis & Everh.) Rossman & W.C. Allen]	'I-214', 'I-455', surviving "Canadians", 'Pan', 'BL Costanzo'	Genetic Chemical
1960s, then occasional	3	Leaf mosaic [Poplar Mosaic Virus, PMV]	'Lux', 'Onda', 'Harvard', 'Soligo', 'Dvina', 'Lambro'	Genetic Preventive
Occasional, more since 1990s	2	Phomopsis stem canker [*Diaporthe* spp. (teleomorphs rarely detected)]	more frequently observed on P. ×canadensis clones	Agronomic
Occasional, more since 1990s	2	Cytospora stem canker [*Cytospora* spp. (teleomorphs rarely detected)]	more frequently observed on P. ×canadensis clones	Agronomic
Occasional, more since 2010s	2	Fusarium stem canker [*Gibberella* spp. (teleomorphs rarely detected)]	Not genotype-linked susceptibility	Agronomic
Occasional since 2000s	1	Bacterial twig canker [*Erwinia*-like spp.]	'Raspalje', 'Beaupré', 'Dvina', 'Oglio'	Genetic Agronomic

have a lower quality, thus remaining restricted to some sites of southern Piedmont. In any case, «Carolinians» would have a role in subsequent poplar systems, several years later.

Before the onset of *Venturia* epidemics, soon after the consolidation of such an embryonal cultivation system, stem necroses and cankers appeared in the nursery ever more frequently on plantlets in marginal soils, subsequently ascribed to attacks by *Cryptodiaporthe populea* (Sacc.) Butin, once designated with its anamorph *Dothichiza populea* Sacc. et Br. Such a weakness parasite and similar others, i.e. *Cytospora* spp. and *Phomopsis* spp., triggered a rationalisation of the mostly rough agronomic practices to avoid any stress (Cellerino 2005). But as already mentioned, the true revolution in this ancient poplar system consisted of a deep clonal renewal and derived from a careful selection versus *V. populina* of new *P. ×canadensis* Moench genotypes [formerly *P. ×euramericana* (Dode) Guinier], amongst which 'I-214', 'I-488', 'I-455' and 'I-154' (formerly 'Arnaldo Mussolini', subsequently exported and spread in Argentina) stood out for their growth and quality features.

After the establishment of 'I-214', together with other Euramerican clones, *Venturia* epidemics went into remission and the poplar phytosanitary condition passed through a two-decade period of relative quiescence, favouring an increase of cultivation throughout northern Italy even on usually paddy areas.

However, the "brown spot" physiologic disorder

Table 2 - Chronology of cultivated poplar pests in Italy with basic features (qualitative incidence scale: 1 = low incidence, 2 = moderate, 3 = high, 4 = very high).

Onset period of outbreaks	Present incidence	Pest [scientific name]	Damage	Control strategy
1950s, then often recurring till now	4	Large poplar borer [*Saperda carcharias* (L.)]	Wood quality loss by larval galleries	Chemical Biologic
1950s, then often recurring till now	4	Poplar-and-willow borer [*Cryptorhynchus lapathi* (L.)]	Plantlet loss in the nursery, deformations, wind crash	Chemical
1950s, then often recurring till now	3	Goat moth [*Cossus cossus* (L.)]	Wood quality loss by larval galleries	Chemical Agronomic
1950s, then sometimes recurring till now	2	Poplar jewel beetle [*Agrilus suvorovi* Obenberger]	Malformations and stem ruptures on 1-year plantations	Agronomic Chemical
1950s, then sometimes recurring till now	2	Melanophila stem borer [*Melanophila picta* (Pallas)]	Malformations and stem ruptures on 1-year plantations	Agronomic Chemical
Occasional since 1950s	1	Winter moth [*Operophtera brumata* (L.)]	Early defoliations in plantations	Biologic
Very occasional since 1950s	1	Hornet clearwing moth [*Sesia apiformis* (Clerck)]	Wood quality loss in mature plantations by larval galleries at collar	Chemical
1950s, occasional outbreaks till now	1	White satin moth [*Leucoma salicis* (L.)]	Defoliations of young and mature stands, reduction of annual growth	Biologic
Since 1960s till now with several outbreaks	4	Woolly poplar aphid [*Phloeomyzus passerinii* (Sign.)]	Death of susceptible clone trees especially in mature stands (e.g. 'I-214', 'Pan', BL Costanzo')	Genetic Chemical
Since 1960s sometimes recurring till now	2	Poplar clearwing moth [*Paranthrene tabaniformis* (Rott.)]	Plantlet loss in the nursery, deformations	Chemical
Since 1960s sometimes recurring till now	2	Poplar twig borer [*Gypsonoma aceriana* (Dup.)]	Plantlet loss in the nursery, deformations	Chemical
Since 1960s sometimes recurring till now	1	Leaf-rolling weevil, Vine leaf roller [*Byctiscus populi* (L.), *Byctiscus betulae* (L.)]	Early defoliations especially in P. deltoides plantations	Agronomic
1960s, then occasional	1	Black-back prominent moth [*Clostera anastomosis* (L.)]	Defoliations of young and mature stands, reduction of annual growth	Biologic
Occasional since 1960s	1	Eastern Nycteoline [*Nycteola asiatica* (Kroul.)]	Late damage of apical shoots in nurseries	-
Since 1960s till now with several outbreaks	2	Poplar leaf beetle [*Chrysomela populi* L.]	Plantlet loss in nurseries, growth reductions in young plantations	Chemical Biologic
Occasional since 1970s	2	European corn borer [*Ostrinia nubilalis* (Hübner)]	Plantlet loss in nurseries	-
Since 1970s, progressively growing	1	Willow and poplar lace-bug [*Monosteira unicostata* (Muls. & Rey)]	Defoliations in nurseries, young plantations and SRF stands	-
Since middle 1980s	3	Fall webworm [*Hyphantria cunea* (Drury)]	Defoliations of young and mature stands, reduction of annual growth mainly in P. ×canadensis clones	Biologic Chemical Genetic
Occasional since 1980s	1	Poplar cambium miner [*Phytobia cambii* (Hendel)]	Wood quality loss by cambium larval galleries	-
Since 2000s in central-southern Italy	3	Ambrosia beetle [*Megaplatypus mutatus* (Chapuis)]	Wood quality loss in mature plantations by larval galleries	Pheromone traps Chemical
Last decade, dramatically growing	3	Brown marmorated stink bug [*Halyomorpha halys* (Stål)]	Bark necroses, stem swellings in nurseries and young plantations	Chemical Biologic Pheromone traps
Last decade, growing	2	Japanese beetle [*Popillia japonica* (Newman)]	Defoliations in plantations	Chemical Biologic
Last decade, new introduction	1	Asian long-horned beetle [*Anoplophora glabripennis* Motschulsky]	Wood quality loss by larval galleries, tree death	Eradicative
Last decade, growing	2	Green leafhopper [*Asymmetrasca decedens* (Paoli)]	Foliage yellowing in nurseries	Chemical

of bark tissue appeared for the first time in Euramerican clones 'I-455' and 'I-488' and in some surviving «Canadians», when grown in soils with too much fluctuating groundwater, prefiguring a typical problem of some very incremental clones that would occur again thirty years later, during the Eighties, with much more dramatic incidence. During the Fifties, the exploitation of suitable clones of the *P. deltoides* parent (Sekawin 1963), such as 'Lux', 'Onda' or 'Harvard', was limited after they were observed susceptible to Poplar Mosaic Virus (PMV), a parasite that induces leaf mosaic and other foliar teratoses, since eradication measures of nursery infected material was still approximate.

Again in the Fifties, pest attacks also acquired importance, such as *Agrilus suvorovi* Obenberger and *Melanophila picta* (Pallas) on first-year plantations, in addition to an increasing occurrence of other wood borers, like *S. carcharias* and *C. cossus* in mature plants or *C. lapathi* in nurseries. Such a trend was possible because of the still deficient tools for chemical control at that time in association with a growing number of infestation sources.

From Marssonina leaf spot to Melampsora rusts: the chemical control era

As already stated, intensive poplar cultivation until the early Sixties was not free from pathogens and pests, but they were sporadic or with incidence restricted to secondary clones. The widespread 'I-214', together with other Jacometti clones selected against *V. populina* as well, ensured good wood production suitable for the most remunerative use, i.e. plywood, and had no outstanding limiting factor if adequate agronomic practices, meanwhile experimented and introduced into ordinary cultivation, were carried out. In the two positive decades 1940-1960, these plantations had an expanding trend which brought the total cultivated surface to more than double, at about 200,000 ha in 1963, the year of the first report in Italy of *Drepanopeziza brunnea* (Ellis & Everh.) Rossman & W.C. Allen [syn. *Marssonina brunnea* (Ellis & Everh.) Magnus] (Castellani and Cellerino 1964).

The fungus soon increased in the whole Po Valley in only one year affecting various Euramerican clones, including 'I-214', and the surviving «Canadians» in the meantime subjected to a decreased inoculum pressure of *V. populina*; according to the clone considered, Marssonina leaf spot caused production losses of between 20% and 50% (Castellani and Cellerino 1969). Typical of the pathogen are roundish brown spots (Fig. 2), smaller than 1mm, appearing on the leaf upper side, progressively confluent to confer to the foliage a characteristic bronze colouring (hence the Italian disease name "*bronzatura*"). The productive damage in terms of incremental loss is connected with impaired transpiration and with a reduction of photosynthetic efficiency, and subsequently with an early phylloptosis. *Marssonina* pressure had a selective effect on cultivated Euramerican clones, since the other Jacometti clones and the surviving «Canadians» resulted very susceptible to it and were soon given up, at least in Italy. Instead 'I-214', although susceptible as well, demonstrated a level of tolerance that, with the aid of phytoiatric treatments, preserved it as the «monopolising» clone of Italian classical poplar cultivation. Its plasticity and versatility in several microclimates and soils determined its dominance for the subsequent fifty years, except for some districts like Lomellina where clones of Canadian feature remained (e.g. 'BL Costanzo').

Figure 2 - Poplar leaves infected by *Marssonina brunnea*.

But without the fundamental support of phytoiatric innovations, in those years fully expanding, such a success of 'I-214' would not have been possible. In a period when ecological awareness was far from influencing agricultural management, Marssonina leaf spot was tackled by introducing treatments with fungicides into cultivation containing new active ingredients just synthetised (e.g. dithiocarbamates maneb and mancozeb), and applied with irrorating devices in fast technological evolution, sometimes even with aircraft (Cellerino 1979, Cellerino and Vidali 1981). The control of Marssonina leaf spot, in a formula that became traditional in several years of implementation, included timetabled preventive treatments, the first of which was carried out at leaf distension and followed by three others, or even four in the eastern Po Valley, by the beginning of July. During the Eighties and Nineties, such a restrictive approach was mitigated thanks to advances in knowledge of biology and epidemiology of the parasite, and to the introduction of systemic fungicides also provided with curative action, such as dodine or hexaconazole; in a context of guided control (Giorcelli and Vietto 1992), it was thus possible to modulate the treatments according to the occurrence of an action threshold (in terms of symptomatic scale) and meteorological parameters with the aid of tackifiers and wetting compounds. Besides, it was argued that the control of Marssonina leaf spot is economically justified only in young growing plantations and in combination with suitable agronomic practices (Giorcelli and Vietto 1998).

The «chemical charge» in poplar cultivation was further incremented by the ever more frequent infestations from the Sixties of the woolly aphid, *Phloeomyzus passerinii* (Sign.), which involved additional applications on trunks of mixtures of white mineral oil and specific aphicides (Lapietra and Allegro 1981). Its infestations may be very incident owing to the several generations following each other during the vegetative season, visible for their abundant white waxy secretion with woolly appearance on the trunk surface, which may even induce the death of mature trees by progressive necrotising of cortical tissues (Fig. 3). Reported in Italy since 1936, for some decades only occasional, it became progressively recurring soon after the first epidemics of *D. brunnea* owing to the expansion of the new *P.* ×*canadensis* clones previously selected against *Venturia*, which on the contrary resulted very susceptible to the aphid, 'I-214' included (Table 2), thus pointing out the risk associated with a clonal selection urgently forced by an epidemic emergency instead of being designed with a systematic approach. In the meantime, nurseries also had their inputs for heavy chemical interventions, because of more frequent outbreaks of *Paranthrene tabaniformis* (Rott.), *Gypsonoma aceriana* (Dup.) and of the aforesaid *C. lapathi* on stems and of *Chrysomela populi* L. on foliage, not seldom with death of plantlets; but since the Eighties, especially because of the resurgence of an ancient poplar disease, i.e. leaf rusts from *Melampsora* spp., unmistakable for its orange-yellow pustules (uredinia) appearing on leaves that in case of strong attacks spread a fine «rusty» powder all over the foliage (Fig. 4). The old dominant population of *M. larici-populina* Kleb., designated as "Europe 1" (E1), and *M. allii-populina* Kleb. had been in equilibrium at low levels of infection with Euramerican clones for several decades, but the appearance of the new physiological E3 race broke such quiescence increasing the infections to high levels of incidence above all in the nursery. As for guided control of Marssonina leaf spot, treatments were applied according to an action threshold (a few uredinia on the lower leaf page) with hexaconazole or other suitable fungicides, in succession till September.

Figure 3 - Poplar trunk infested by woolly aphid, *Phloeomyzus passerinii.*

Figure 4 - Poplar leaves with uredinia produced by *Melampsora larici-populina.*

The E3 race was probably already present in the poplar pathosystem, but it found new hosts with higher susceptibility in the clones meanwhile selected or repurposed against Marssonina leaf spot alongside chemical control, i.e. 'Lux' and 'Onda' among *P. deltoides*, 'Neva' and 'Luisa Avanzo' among *P.* ×*canadensis*, and some other clones with Carolinian character. The increased inoculum pressure of E3 race from these sources induced heavier rust attacks on 'I-214' as well. Again, the fruits of a non-systematic and non-fully designed genetic selection showed themselves vulnerable versus other adversities not fully known or tested.

Table 3 - Levels of resistance of MSA clones, with improved environmental sustainability, versus the main biotic adversities (qualitative resistance scale: "--" = very susceptible, "-" = susceptible, "0" = tolerant, "+" = resistant, "++" = very resistant).

Species or hybrid	Clone	Pathogen or pest						
		Shoot blight	Rusts	Leaf spot	Dothichiza canker	"Brown spots"	PMV	Woolly aphid
P. ×canadensis	'I-214'	++	0	-	0	0	++	--
P. trichocarpa × P. ×generosa	'AF8'	++	+	++	+	+	++	+
P. ×canadensis	'Aleramo'	+	++	++	+	+	+	+
P. ×canadensis	'Brenta'	++	0	++	0	0	+	++
P. ×canadensis	'Diva'	+	++	++	+	+	+	++
P. deltoides	'Dvina'	++	+	++	+	+	-	+
P. deltoides × P. maximowiczii	'Eridano'	++	++	++	++	++	++	++
P. deltoides	'Harvard'	++	+	++	++	++	-	+
P. ×canadensis	'Koster'	++	+	0	+	+	++	++
P. ×canadensis	'Lambro'	++	0	++	++	+	-	++
P. deltoides	'Lena'	++	+	++	++	++	0	+
P. deltoides	'Lux'	++	+	++	++	++	-	++
P. ×canadensis	'Mella'	++	0	++	0	0	+	+
P. ×canadensis	'Moleto'	+	++	++	+	+	+	++
P. ×canadensis	'Mombello'	+	+	++	+	+	+	++
P. ×canadensis	'Moncalvo'	+	++	++	+	+	+	++
P. deltoides	'Oglio'	+	++	++	++	++	+	++
P. deltoides	'Onda'	++	+	++	++	++	-	+
P. ×canadensis	'San Martino'	++	+	+	+	++	--	+
P. ×canadensis	'Senna'	+	++	+	+	+	++	++
P. deltoides × P. ciliata	'Sile'	+	++	++	++	++	++	++
P. ×canadensis	'Soligo'	++	++	++	++	++	-	+
P. ×canadensis	'Stura'	+	++	++	++	++	++	++
P. deltoides × P. ×canadensis	'Taro'	++	+	++	+	+	0	++
P. ×canadensis	'Tucano'	+	++	++	+	+	+	++
P. alba	'Villafranca'	++	++	++	++	++	++	++

The increased rust incidence of the Eighties was soon associated with a resurgence of Dothichiza stem canker (Fig. 5), once limited to marginal soils and especially affecting «Carolinians» before *Venturia* arrival. It was found that rust attacks, besides causing direct quantitative damage in terms of decreased annual growth, may induce a predisposition to *C. populea* infections by reducing twig lignification and accumulation of preserving compounds before winter dormancy (Giorcelli et al. 2012). This was the first case, in poplar cultivation, of a statistically significant association between two different diseases on distinct plant tissues and in subsequent times.

Besides being heavily affected by *M. larici-populina* E3 attacks, the very promising clone 'Luisa Avanzo' showed itself as very subjected to "brown

Figure 5 - Poplar twig with necrotic areas corresponding to infections by *Cryptodiaporthe populea.*

spot" physiologic disorder, already observed throughout the Fifties on 'I-455' and 'I-488', but not immediately recognised, for a while putatively ascribed to some bacterial agents still to be found. Instead, the "brown spot" disorder was progressively outlined as a paradigmatic syndrome of the times, characterised for climate by increasingly irregular precipitations and extended summer drought, and for agronomy by high inputs of nitrogen fertilisers that pushed to the extreme growth physiologic parameters of some very productive genotypes (Anselmi 1990). By the end of the Eighties, therefore, 'Luisa Avanzo', and the related expectations of poplar cultivators and stakeholders of having a new production standard, faded.

From direct control of diseases and pests towards integrated management: the sustainable and genomic era

Between the end of the Eighties and the beginning of the Nineties, the pathosystem of modern poplar cultivation was in the following situation: Marssonina leaf spot in slight decrease with respect to the peaks of the first epidemics, maintained in any case under a suitable level of incidence by chemical control; woolly aphid recurring with several outbreaks, limited by chemical control as well; leaf rusts constantly widespread in nurseries, and even more incident in short rotation forestry, equally limited by chemical treatments; poplar-and-willow borer (*C. lapathi*) periodically raging in nurseries as well; *S. carcharias* and *C. cossus* occasionally but often badly affecting wood usability. This referring only to the main biotic adversities, without going into detail on the less incident ones, however on the whole frequently present in plantations or nurseries (Tables 1 and 2). A comprehensive increase of outbreaks of new pests, however, was recorded in these three decades indeed owing to the enhanced trading of vegetal material throughout the world, but even and especially because of the increasing periods of drought, that predispose plants to attacks by insects, and the on-average increased temperatures during the vegetative season that enhance their generations and voltinism (Deutsch et al. 2018).

As regards non-specific pests, heavy defoliations of young and mature plantations by fall webworm, *Hyphantria cunea* (Drury), date back to the middle Eighties and have occurred, with some fluctuations,

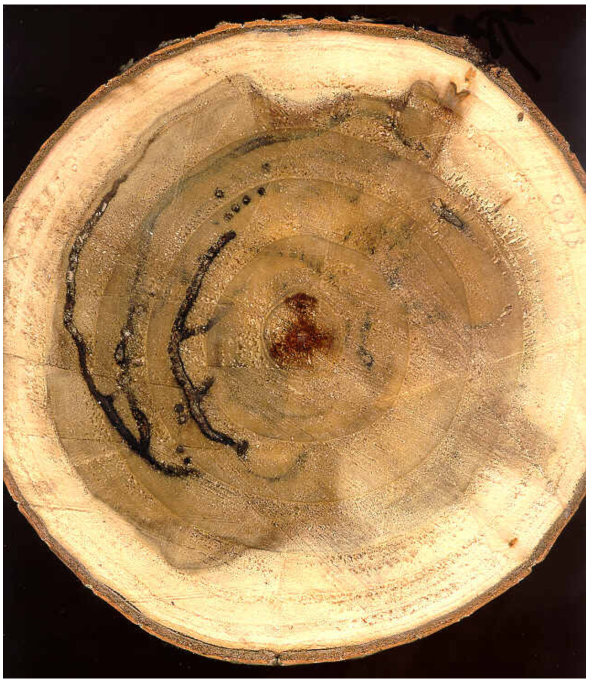

Figure 6 - Transversal section of poplar trunk showing galleries of Megaplatypus mutatus.

until today, especially on *P.* ×*canadensis* clones, whereas *P. deltoides* clones appear less subjected (Allegro 2017). Among wood borers, although still absent in northern Italy probably because of its temperature requirements, the Ambrosia beetle, *Megaplatypus mutatus* (Chapuis), has been raising great concerns since the early 2000s for its destructive potential of timber in mature plantations (Fig. 6; Alfaro et al. 2007). Coming to the present day, the last but already very important threat is made by the brown marmorated stink bug, *Halyomorpha halys* (Stål), whose first infestations on poplar were reported in 2015. Very polyphagous, its incidence was observed to be higher on poplar rows closer to corn fields probably because corn is preferred as host and here one finds the most elevated concentration of bugs (Giorcelli, in press). Concentrated infestations of *H. halys* may induce, with its irritant saliva, extended bark necroses and dieback of affected plants, both in the plantation and in the nursery (Fig. 7).

No new fungal pathogens, on the contrary, have been reported on poplars in the last three decades, apart from *Melampsora magnusiana* G.H. Wagner

Figure 7 - Poplar trunk infested by *Halyomorpha halys.*

which was recently reported for the first time in Italy on white poplar (Giordano et al. 2017), however not incident on commercial cultivation. A certain resurgence of *V. populina* was observed in the Nineties especially in some districts of the eastern Po valley and Friuli-Venezia Giulia where clones of Canadian character (e.g. 'Stella ostigliese', 'Adige') were cultivated, but eventually the disease regressed again with the almost complete abandonment of such clones. The same climate trend that contributed to the aforesaid more frequent pest outbreaks probably plays a predisposing factor to the recent increased incidence of stem cankers by *Cytospora* spp., *Phomopsis* spp. and *Fusarium* spp., not new on poplar, the last one especially worth being monitored because it has shown virulence on various genotypes, not only the old *P.* ×*canadensis* clones.

Hypoxylon cankers from *Entoleuca mammata* (Wahlenb.) J.D. Rogers & Y.M. Ju [syn. *Hypoxylon mammatum* (Wahlenb.) P. Karst.], although object of recent attention and categorisation (EFSA Panel on Plant Health 2017) for its high incidence in North American aspen forests, is only occasionally reported in northern and central Europe, including Italy, where it is restricted to the Alpine belt, since the preferred genotypes are section *Populus* Eckenw. species (white poplars and aspens) not used in our intensive poplar cultivation. Similarly, an exotic leaf rust agent, *Melampsora medusae* Thüm., widespread in North and South America, has currently been reported only in Belgium, France and Portugal (EFSA Panel on Plant Health 2018a) but it has not been observed until now in Italy.

As regards bacterial diseases, the oozing canker caused by *Xanthomonas populi* pv. *populi* (Ridé) Ridé & Ridé, typical on genotypes of Belgian origin, is still absent in Italy, probably owing to the absence of suitable clones, but since the early 2000s swellings and cankers have occasionally appeared on plantlets of Interamerican clones (*P.* ×*generosa* A. Henry) putatively ascribed to bacteria of *Erwinia* group, and possibly connected with a vector role of some insects.

A very variegated scenario of adversities, which can only be faced with multiple management solutions, since a non-systematic genetic selection or a heavy chemical approach are clearly not further pursuable. Actually, several ways of pathosystem and entomofauna management have been explored for years, at different stages of advance:

1) *Exclusion of exotic pests and pathogens.* The efficiency of exclusion methods is fundamental not to undermine the efforts of genetic selection performed in these two decades. For example, the very feared *Sphaerulina musiva* (Peck) Quaedvl., Verkley & Crous (syn. *Septoria musiva* Peck), agent of leaf spots and Septoria stem canker, widespread in North America and Argentina, is today absent in Europe in spite of the great clamour on its supposed presence, although *P.* ×*canadensis* clones are reported as susceptible hosts. Broad regions in Europe have a suitable climate for the pathogen, with a probable huge impact on poplar cultivations of the continent, thus great effort is needed to detect it in imported material even at first infection stages by routine PCR techniques (EFSA Panel on Plant Health 2018b).

2) *Systematic genetic improvement.* Beginning from the end of the Eighties, poplar genetic improvement was planned according to a multistage design, called "recurring semi-reciprocal selection" (Bisoffi and Gullberg 1996), which included several cycles of genotype breeding inside and between *P. nigra* L. and *P. deltoides*,

with a progressive achievement of data on growth characters and on resistances versus the main diseases or pests. Such a programme had a double objective, aiming on one hand at maintaining a broad genetic variability and at obtaining improved populations of European and American parents, and on the other hand at selecting new commercial clones suitable for ordinary cultivation or for biomass short rotation. The last goal was fulfilled after more than twenty years with the achievement of the so called "MSA clones", in large part included in *P. ×canadensis*, characterised by improved environmental sustainability thanks to their resistance or tolerance versus the main poplar biotic adversities (Table 3), which allow reduced inputs of fungicides or insecticides into cultivation. Surface fractions of MSA clones are recommended in rural development plans of several regions to achieve cultivation grants. The contemporary presence of several clones should also prevent a fast spread of epidemics, as occurred in the past with Marssonina leaf spots.

3) *Marker Assisted Selection (MAS)*. Poplar genetic improvement in general is delayed by the multiannual lifecycle of the genus, implying some years for detection of dendrologic features and for flowering, and as regards research of resistances it is limited by the necessity to perform separated inoculation tests on large numbers of progenies. The achievement of molecular markers for loci associated with the expression of resistance versus the main pathogens or pests would enormously facilitate and accelerate selection protocols. As examples, loci of qualitative and quantitative resistance to *M. larici-populina* have been mapped and for some of them molecular markers are already available (Cervera et al. 1996, Jorge et al. 2005); likewise, quantitative trait loci associated with resistance to woolly aphid were found (Carletti et al. 2016) and putatively usable with markers under investigation for breeding programmes.

4) *Non-conventional pest management.* Against some pests, potentially very damaging but not easily predictable, treatments with synthetic compounds would be expensive and ecologically unsustainable. An efficient biological control can be pursued using toxins of the Gram-positive bacterium *Bacillus thuringiensis* Berliner, the insecticidal activity of which has been known for more than thirty years (Aronson et al. 1986), but only in recent years available in commercial preparations. *B. thuringiensis* insecticidal proteins, classified into some groups according to their mode of action, are especially active against Coleoptera and Lepidoptera; among poplar pests, they have been used on *H. cunea* and *C. populi* (Allegro 2017), but the treatments must not be extensive since recently cases of field-evolved resistance have been observed in some non-poplar pests (Peralta and Palma 2017). Instead, a biological control of the Japanese beetle, *Popillia japonica* (Newman), object of mandatory defence since 2016, could be achieved by entomoparasitic nematodes able to threat larvae in soil (Ciampitti et al. 2016). The management of *H. halys* is more composite and includes the use of pheromone traps to monitor population levels, protective nets, and a suitable dispersion of oophagous parasitoids still to be improved (Roversi et al. 2016).

At the end of this even summary review, we emphasise the need to further investigate the genetic connections between host and parasite, especially for biotrophic pathogens like *Melampsora* rust agents, where great advantage could be achieved by using epigenetic mechanisms of gene expression, and the rhizosphere and phyllosphere microbiota with the new possibilities offered by metagenomics. A sustainable poplar cultivation means complexity, in a condition that must emulate the homeostatic regulating systems of natural ecosystems without loss of production: complexity of cultivated material, but also of pathogen and pest management.

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