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Breeding and improvement of black locust (*Robinia pseudoacacia* L.) with a special focus on Hungary: a review

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Black locust (*Robinia pseudoacacia* L.) is a multipurpose tree species native to North America commonly planted worldwide for its resistant and durable wood, rapid growth, site tolerance, honey production, and other qualities. However, caution is warranted when planting the species outside its native range due to its potential invasiveness with respect to the native flora. Many countries, particularly Hungary and China, have been conducting forestry research on black locust for decades to increase black locust yields, nectar production, and stem quality. The main breeding objectives, such as fast growth, superior trunk quality or higher nectar production, have already been achieved. Existing reviews on this tree species do not cover the whole research history of breeding, making a comprehensive review increasingly critical to identify research gaps, trends, and drawbacks. The present study offers a systematic analysis of nearly 100 papers spanning the last century and the most recent research on black locust improvement. This study also includes a detailed summary of the available cultivars and clone selections worldwide.

Keywords: Tree Improvement, Selected Cultivars, Wood Production, Apiculture

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Introduction

Arrival and presence in the Old World

Black locust (*Robinia pseudoacacia* L.) is native to eastern North America and was introduced to Europe in the early 17th century (Sitzia et al. 2016). Since then, black locust has been naturalized (*i.e.*, it can form self-sustained populations in a given environment without human intervention) in all sub-Mediterranean and temperate zones, including almost every European country, 13 Asian and six African countries, along with Argentina, Chile and New Zealand (Keresztesi 1988, Demené & Merzeau 2007, Pyšek et al. 2009, Cierjacks et al. 2013, Nicolescu et al. 2020, Puchalka et al. 2021). The species is widespread and is of significant economic importance in Hungary, Romania, Ukraine, Poland, Germany, France, Italy, Serbia, Bulgaria, China and South Korea (Nicolescu et al. 2020, Puchalka et al. 2021, Ciuvat et al. 2022). Globally, it is the second most commonly planted tree species after *Eucalyptus* spp. (Huntley 1990, Wojda et al. 2015, Nicolescu et al. 2020). Black locust has spread over 2.44 million hectares beyond its original distribution area (Brus et al. 2019). The climate is the primary barrier preventing further expansion, followed by legal restrictions connected to human interventions on the species (Nicolescu et al. 2020).

Main ecological properties of black locust

Black locust is a typical fast-growing tree species; it is drought-tolerant and adaptable to many sites and climates (DeGomez & Wagner 2001). Despite its fast growth rate, black locust has hard, dense, rot-resistant wood suitable for sawn wood products, barked or belted poles, vineyard posts and other applications (McAlister 1971, Keresztesi 1988, Huntley 1990, Nicolescu et al. 2020). Its rapid growth and high energy density are also advantageous for short-rotation energy plantations (Miller et al. 1987, Barrett et al. 1990). Black locust also fixes nitrogen, and its prolific flowering ensures abundant nectar production (Keresztesi 1988).

Black locust originates from a humid temperate climate where annual precipitation ranges from about 1020 to 1830 mm and frost-free days number 150 to 210 (Huntley 1990). Nevertheless, the species is highly drought tolerant and survives in European regions with 500 to 550 mm total annual rainfall (Mantovani et al. 2014, 2015, Nicolescu et al. 2020, Kraszkiewicz 2021, Ábri et al. 2022). However, the native North American range for black locust is 5° to 10° further south than where it is grown in Europe (Bartha et al. 2008, Huntley 1990). Consequently, it is susceptible to frost in Hungary. In the northern reaches of its European range, it usually experiences dieback, resulting in a second bloom that drastically reduces annual black locust honey production (Keresztesi 1988). According to several authors (Thurm et al. 2018), black locust could provide an alternative to beech (*Fagus sylvatica* L.) and silver fir (*Abies alba* Mill.) in the future if the predicted northward shift due to temperature increases of 2.9 °C or 4.5 °C occurs. In North America, the species prefers mainly nutrient-rich, moist, loamy, limestone-origin soils. As in Europe, it grows predominantly on loamy or silty loam soils (Huntley 1990). The tree prefers neutral to slightly acidic pH and well-aerated soils. Compacted clayey soils inhibit growth, and the species does not tolerate waterlogging (Járó & Lengyel 1988, Zhang et al. 2006, Vítková et al. 2015). Black locust is a light-demanding tree species; without intervention, other shade-tolerant tree species overgrow it during the succession phase when it reaches 70 years, leading to stand collapse (McAlister 1971, Huntley 1990).

Despite black locust's positive attributes, many countries – including the Czech Republic, Switzerland, and Great Britain – have introduced legal restrictions against the species due to its invasive nature (Vítková et al. 2016). Black locust is an early succession invader in its native habitat. Its success in disturbed sites determines its massively successful colonizing tendencies beyond its native range. It threatens dry and semi-dry grasslands, some of the most species-rich and endangered habitat types in such regions (Vítková et al. 2017). Unfortunately, black locust also threatens the extinction of many endangered light-demanding plants and invertebrates due to the changes it imposes on the light regime, microclimate and soil conditions. A stratified approach combining tolerance in some areas and strict eradication in valuable sites may provide an optimal future solution for achieving the sustainable coexistence of black locust, people and nature (Vítková et al. 2017, Campagnaro et al. 2018, Wohlgemuth et al. 2022).

The question of black locust breeding, main objectives and methods

Clone improvement for tree plantations is the most prominent field in black locust breeding. Tree plantations, forest plantations, plantation forests, timber plantations or tree farms are forests planted for high-volume wood production, usually using one tree type to form a monoculture forest. Tree plantations belong to the plantation forest research field, and the most significant criteria can be summarised in four points. The first point is that a pre-defined range of quality forest target assortments and primary (forest) wood products are produced in large quantities. The second is a systems approach, which presupposes an extensive growing technology allowing for the preplanning of work operations. The third is a significantly shorter growing period compared to natural forests due to the specific elements of growing (fast-growing tree species, varieties, artificial afforestation technologies, etc.); and the fourth is that the economic goal of growing trees is to produce a higher net income in the shortest possible time. Appropriate cultivar assortment is a pillar of plantation forestry technology. In addition to the well-defined requirements arising from the wood industry, several notable characteristics and breeding objectives deserve mention. For example, black locust is a promising apiculture tree species due to its remarkable honey production (Keresztesi 1988, Nicolescu et al. 2020). It is also suitable for landscape reclamation and phytoremediation after land degradation (Nicolescu et al. 2020, Hu et al. 2021).

Given the above, researchers working on black locust genetic improvement must focus selection on fast-growing individuals with optimal trunk shapes for milling and other wood industrial or biofuel processing. Another breeding aspect is higher nectar production capabilities through broader crown shapes or more predictable flowering periods. Selection should also consider the ability to survive future climate change-induced distribution shaping (Kutnar & Kobler 2013, Giuliani et al. 2015, Dyderski et al. 2017).

Black locust breeding programmes aimed at improving wood quality, increasing biomass production for energy purposes and enhancing drought tolerance have been ongoing in many countries for decades (Hanover et al. 1991, Liesebach et al. 2004, Nicolescu et al. 2018, Ábri et al. 2021, Szyp-Borowska et al. 2022). Hungary is currently the leading European country in black locust genetic improvement programmes (Rédei et al. 2020, Keserű et al. 2021, Ábri et al. 2021, 2022). On the other hand, significant breeding activity has also emerged in China, which has developed over 100 newly-bred black locust cultivars (Dong et al. 2019). A comprehensive overview of the currently available clonal assortment is useful not only for plantation forestry experts and their practice but also from the perspective of tree improvement and forestry research through future clonal tests, the application of novel breeding techniques or evaluating the potential plant resources for directional crossing.

Methods

This review offers a systematic analysis of 100 international studies on black locust improvement encompassing the past and present. Since black locust breeding has a long tradition in Hungary, it also reviews genetic improvements in this country.

The present study used the Google™ search engine to search for subject literature with the following keywords: black locust, cultivars, breeding and tree improvement. It also cited original papers and reviews published in peer-reviewed scientific journals and some important conference references. The study complemented this work with rare and only locally available printed literature on past breeding activity. Finally, it addressed the subject with additional information concerning the ecological properties, invasiveness, and promising molecular marker techniques for future application.

International overview of black locust breeding objectives

Historically, the genetic improvement of black locust – focusing primarily on wood quality for industry – has involved research on ship mast locust (*Robinia pseudoacacia* var. *rectissima* Raber). This black locust variety has straight stems and superior resistance to biotic pest attacks, making it an excellent material for masts. However, ship mast locust is a poor seed producer (a characteristic that may be beneficial for other reasons) and propagates almost entirely by vegetative means (Raber 1936, Hopp 1941, McAlister 1971).

Black locust breeding accelerated in the middle of the 20th century in several countries, particularly in non-native regions. Countries in these regions include Hungary (Keresztesi 1988), Romania (Nicolescu et al. 2018), Germany (Schröck 1965, Schneck 2010), Bulgaria (Kalmukov 2011), Greece (Dini-Papanastasi & Panetsos 2000) and China (Dong et al. 2019). In general, southern European countries have used the species for fodder and energy crops, while the north focuses more on wood products (Nicolescu et al. 2020). Since honey production is a significant aspect in Central Europe (Keresztesi 1988) and South Korea (Lee et al. 2007), efforts in these places follow trends associated with that black locust breeding aspect. Tab. 1 summarises the main breeding objectives and highlights the most important countries. The following discusses breeding efforts in individual countries.

Black locust breeding in France focused primarily on growth enhancement of short rotation energy plantations and ornamental use (Borde 2018, Nicolescu et al. 2020). In Great Britain and the United States, the main objectives of black locust breeding were rapid growth and pest resistance (Huntley 1990, DeGomez & Wagner 2001). Genetic improvement in Hungary and Romania concentrated mainly on fast growth, high-quality straight trunks and extended flowering periods, as well as increasing the number of inflorescences and resistance traits (Keresztesi 1988, Rédei et al. 2017, Nicolescu et al. 2018, Ábri et al. 2021, 2022). Poland and Bulgaria emphasised straight-stemmed individuals (Klisz et al. 2014, Wojda et al. 2015) and conducted some studies on black locust micropropagation (Szyp-Borowska et al. 2016, Szyp-Borowska et al. 2020). Greece uses black locust primarily for fodder production and short rotation energy plantations (Dini-Papanastasi & Papachristou 1999); fittingly, the main breeding objectives there have been drought tolerance (Aravanopoulos 2010, Dini-Papanastasi et al. 2012), biomass production (Dini-Papanastasi 2008) and outstanding growth potential (Dini-Papanastasi 2004). Other countries such as Italy, Hungary and Germany, have also studied black locust biomass production and energy use (Paris et al. 2006, Facciotto et al. 2009, Rédei & Veperdi 2009, Rédei et al. 2010, 2011, Maltoni et al. 2012, Straker et al. 2015, Crosti et al. 2016, Giulietti 2016, Vítková et al. 2016, Nicolescu et al. 2020).

Beyond Europe, breeding activity has also

Tab. 1 - The most important objectives in black locust breeding with the relevant countries and varieties. (*): new candidates; (**): the present study did not mention all the Chinese black locust cultivars; more details can be found in Dong et al. (2019).

Breeding aims	Relevant countries	Possible varieties, cultivars or promising candidate cultivars	References
Industrial wood, tree plantations	Hungary	‘Jászkiséri’, ‘Kiskunsági’, ‘Nyírségi’, ‘Üllői’ ’,	Keresztesi (1988), Rédei et al. (2017), Ábri et al. (2021)
		‘Vacsi’*, ‘Homoki’*, ‘Bácska’*	Keserű et al. (2021)
		‘PL251’*, ‘PL040’*, ‘NK1’*, ‘NK2’*	Ábri et al. (2022)
		‘Turbo OBE’*	Pataki et al. (2016)
	Romania	*R. pseudoacacia* var. *oltenica*	Ciuvat et al. (2022)
Energy plantation, biofuel	Greece	*R. pseudoacacia* var. *monophylla*: ‘A-7B(6)’, ‘B-2B(3)’, ‘A-B(3)’, ‘A-8A(3)’	Dini-Papanastasi (2004), Aravanopoulos (2010)
	Hungary	‘Turbo OBE’*	Pataki et al. (2016)
Afforestation on marginal sites and arid regions	Hungary	‘Vacsi’*, ‘Homoki’*, ‘Bácska’*	Keserű et al. (2021)
	Greece	*R. pseudoacacia* var. *monophylla*: ‘A-7B(6)’, ‘B-2B(3)’, ‘A-B(3)’, ‘A-8A(3)’	Dini-Papanastasi (2004), Aravanopoulos (2010)
	China	‘Jiangan 1’, ‘Danye’, ‘Honghuahuai’, ‘Chuihuai’, ‘Changye’, ‘Xiongyali’, ‘Xiaoye’, ‘Beilin’, ‘Shilin’, ‘Hebei’, ‘Minquan’, ‘Henanjiangen’, etc.**	Dong et al. (2019)
Land restoration, remediation	Greece	*R. pseudoacacia* var. *monophylla*: ‘A-7B(6)’, ‘B-2B(3)’, ‘A-B(3)’, ‘A-8A(3)’	Dini-Papanastasi (2004), Aravanopoulos (2010)
	Hungary	‘Appalachia’	Keresztesi (1988)
Apiculture, honey production	Hungary	‘Kiskunsági’	Keresztesi (1988)
		‘Mézelő Grófi’*, ‘Mézelő Illatos’*, ‘Debreceni-2’*	-
Forage	Greece	*R. pseudoacacia* var. *monophylla*: ‘B-A(13)’ and ‘B-6A(8)’	Dini-Papanastasi (2004)
Ornamental	Australia	‘Frisia’	Glen (2002)

emerged in China, with a specific effort to select varieties that tolerate drought and low soil nutrient levels (Yang et al. 2020). A recent complex physiological, biochemical and proteomic study in tetraploid black locust evaluated salinity stress tolerance (Luo et al. 2017). Guo et al. (2022a) analysed the variation of phenotypic and physiological traits of black locust seedlings originating from 20 provenances in USA to select elite germplasm resources. Guo et al. (2022b) combined the evaluation of phenological traits with genotype data to construct a core germplasm collection for breeding and research purposes. Both studies concluded that black locust presented high genetic variation among and within provenances, and the applied method was appropriate for selective breeding and establishing core collections. A preliminary study by Lu et al. (2015) examined the feasibility of intraspecific crossbreeding; however, the initial result indicated low crossability among the tested five genotypes even though black locust is predominantly considered a highly outcrossing tree species.

Much of the research in South Korea has sought to improve the black locust morphology and the cytological characteristics of tri- and tetraploid varieties, whether spontaneously or induced by colchicine (Huntley 1990). According to Keresztesi (1988), some cultivars in South Korea were bred for forage, mainly by mutational breeding, resulting in a lack of thorns, increased leaf area, and high protein content. The use of polyploid black locust for forage breeding also arose in Hungary (Kopecky 1966). Based on cytological examinations, several mixoploid and tetraploid individuals were identified. In the case of mixoploids, even the chimaera phase could be proved. The selected polyploid genotypes displayed unique leaf morphological properties, including a larger-than-average leaf area due to the increased size and thickness of the leaf blade. Although the selected genotypes are no longer available, the conclusion that the growth rate of polyploid clones was constantly lagging behind the diploid clones can be a topic in future research. Polyploid clones were also investigated in Germany (Ewald et al. 2009) by focusing on frost and drought tolerance and increased herbicide resistance, leading to the development of an effective lab method for pre-screening large numbers of plants with higher ploidy levels.

Black locust breeding in Hungary

Black locust arrived in Hungary over three centuries ago. In the 1930s, Rudolf Fleischmann (originally a grain breeder whose research work vanished during World War II) was the first to attempt a black locust breeding programme. From the 1960s onwards, several breeders in Hungarian forest research – namely Ferenc Kopecky, Béla Keresztesi, Zoltán Marjai, Imre Kapusi and Károly Rédei – achieved outstanding results in black locust improvement (Fleischmann 1933, Keresztesi 1983, 1988, Rédei 2013).

Three periods of Hungarian black locust improvement are distinguishable. The first was the breeding of ship mast-type black locust varieties started by Béla Keresztesi and his co-workers in the middle of the 20th century and dominated by the selection of superior plus trees (selection breeding method) from various stands in Hungary, resulting in several black locust cultivars such as ‘Üllői’, ‘Nyírségi’, ‘Jászkiséri’, ‘Kiskunsági’, and ‘Appalachia’ (the last is the only one introduced directly from USA). These cultivars are mainly clonal mixtures of numerous superior trees and have been proven in many experiments (Keresztesi 1988, Rédei 2013, Rédei et al. 2017, 2020, 2021, Ábri et al. 2021). The results show that some of these cultivars (‘Jászkiséri’ and ‘Üllői’) can be grown on semi-marginal sites, increasing the stem quality by 12-15% on average (Fig. 1). A yield table for selected black locusts was also formulated (Rédei et al. 2021). Béla Keresztesi was also involved in breeding for apiary development and selecting beekeeping varieties, such as *Robinia × ambigua* ‘Rózsaszín AC’ and *R. pseudoacacia* ‘Debreceni-2’, but most of his documented varieties were recommended for wood production (Keresztesi 1983, 1988).

A new breeding programme led by Károly Rédei in the 1990s began the second period. This research selected relatively drought-tolerant specimens from marginal (semi-arid) Hungarian sites (Danube-Tisza Interfluve) and propagated them *via* micropropagation (Rédei et al. 2002, Nicolescu et al. 2018). The research resulted in five

Fig. 1 - 30-year-old 'Üllői' black locust plantation in Eastern Hungary (photo: Zsolt Keserű, 2015)

candidate cultivars ('Vacsi', 'Szálas', 'Oszlopos', 'Homoki', and 'Bácska'). Some of these ('Vacsi', 'Homoki' and 'Bácska') are promising according to our studies conducted to date because they outperform common (seed-originated) black locust in stem quality and yield (Rédei et al. 2013a, 2013b, Keserű et al. 2021). Imre Kapusi and Jenő Németh also launched a new breeding company concurrently in the private sector; the company focused on selecting fast-growing genotypes in the seedling stage from Hungarian forestry nurseries. As a result, the 'Turbo OBE' candidate cultivars were selected after numerous consecutive field experiments (Pataki et al. 2016). These candidates are suggested for biomass purposes and fast-growing industrial wood plantations (Fig. 2).

The third era of Hungarian black locust research started in the late 2010s. A joint project of the Hungarian Forest Research Institute (part of the University Sopron) and Napkori Erdőgazdák Zrt. (Napkor Foresters Private Limited Company) is studying and testing black locust growing technology in industrial tree plantations with four new high-performance black locust clones (PL251 - 'Püspökladányi', PL040 - 'Farkasszigeti', NK1 - 'Laposi', and NK2 - 'Napkori'). The project aims to develop and improve drought-tolerant black locust with rapid juvenile growth and high-quality timber production; traditional forestry inventories are also complemented with plant physiological studies (Ábri et al. 2022).

Fig. 2 - Juvenile micropropagated black locust clones (photo: Zsolt Keserű, 2017)

Parallel with the above, there has been a growing international interest in the field of Hungarian black locust improvement; the shared research, development and innovation (R&D&I) experiences combined with practical knowledge further help to improve Hungarian black locust cultivation (Fig. 3). Several countries have sent researchers and apprentices to Hungary to study black locust growing technology. Many studies and scientific articles have appeared internationally in recent decades (Keresztesi 1988, Rédei et al. 2001, 2002, 2013a, 2013b, 2017, Lee et al. 2007, Keserű et al. 2021, Ábri et al. 2021, 2022), and the export of propagating material of some black locust cultivars and candidate cultivars have been initiated.

This review draws the following important, practice-oriented conclusions based on the discussed published results. First, the growth and yield data at the end of the 30-35th growing season demonstrated that some of the selected black locust cultivars can be grown on semi-marginal sites. Second, root cuttings as a vegetative propagation method have proved suitable for black locust clonal selection. Third, it is possible to (significantly) increase stem quality and the ratio of wood material used for industrial purposes (20-25% on average) by growing selected black locust cultivars. Using cultivars as bee forage can also increase nectar production and honey yield. Fourth, genetic improvement techniques may remove obstacles blocking the widespread use of black locust in some potentially promising countries.

The genetic improvement of black locust: the most important varieties, cultivars and clonal selections

To sum up and complement the previously described breeding efforts, we will review the most significant historical steps in black locust genetic improvements in chronological order by country.

The first cultivar (cv. 'Inermis') was produced in France in 1804, and several other cultivars have been cultivated since: 'Tortuosa' (1810), 'Crispa' (1825), 'Pyramidalis' (1839), 'Unifolia' (1855), and 'Semperflorens' (1871) (DeGomez & Wagner 2001).

Two cultivars recorded in Great Britain are 'Microphylla' (1813) and 'Macrophylla' (1824) (DeGomez & Wagner 2001).

Despite its North American origins, black locust selection in the USA only started in 1930 (McAlister 1971, Huntley 1990, DeGomez & Wagner 2001). 'Dean Rossman' is one variety produced in New York in 1990, but 'Burgundy' (1996), 'Monophylla pendula' (1996), 'Purple Crown', 'Purple Robe', 'Rehderi' and 'Umbraculifera' are also associated with North America (DeGomez & Wagner 2001).

Breeding programmes began in Germany in 1950 (Schneck 2010) and have produced several cultivars. These include 'Aurea' (1859), 'Bessoniana' (1859), 'Monophylla Fastigata' (1880), and 'Pendulifolia' (1860)

(DeGomez & Wagner 2001).

Black locust cultivation in Hungary started in the 1960s (Keresztesi 1988, Rédei et al. 2017). In 2021, the recognised and still available black locust cultivars are ‘Appalachia’, ‘Kiskunsági’, ‘Jászkiséri’, ‘Nyírségi’, and ‘Üllői’ (NFCSO 2021 – see also Tab. S1 in Supplementary material).

Breeding in Romania also started in 1960. Five plantations from five zones covering the whole country were designated for breeding purposes. A total of 25 plus trees (field selection of superior trees compared to the overall stand) were selected (Roman et al. 2020). One noteworthy variety is *R. pseudoacacia* var. *oltenica*, which has outstanding wood production properties (Corneanu et al. 2010, Enescu & Danescu 2013, Budău & Timofte 2015, Nicolescu et al. 2018).

Black locust breeding in Bulgaria began in the 1970s (Kalmukov 2011), and two clones (‘Srebarna’ and ‘Tsarevets’) have been documented. Both genotypes were selected from open-pollinated families in north-central Bulgaria to improve the lineage (Stankova et al. 2020).

China has cultivated over a hundred superior clones and varieties since the 1970s. A recent study found that 110 of the 123 recognized varieties could be genetically distinguished using SSR DNA markers (Dong et al. 2019).

Although there are no exact records of ‘Frisia’ black locust (*R. pseudoacacia* ‘Frisia’) breeding in Australia, the variety was popular there in the 1980s and is still found in Australian gardens and landscapes today. Its other variety – the mop-head acacia (*R. pseudoacacia* ‘Umbraculifera’) – has become a similarly famous and popular tree among residents (Glen 2002).

Black locust breeding in Poland started in the 1990s, with two selected plantations resulting in 34 outstanding specimens and two seed-producing stands (Klisz et al. 2014, Wojda et al. 2015).

In Greece, 30 genotypes from nine open-pollinated families were obtained; however, the initial date of black locust breeding is unknown. From this assortment, 12 individuals were further tested, with particular importance given to clones of *R. pseudoacacia* var. *monophylla*: ‘A-7B(6)’, ‘B-2B(3)’, ‘A-B(3)’, and ‘A-8A(3)’ (Aravanopoulos 2010). One advantage of these clones is that they were selected in a drier, warmer climate and will have a better chance of surviving climate change-induced warming in more northern areas in the future (Dini-Papanastasi & Panetsos 2000, Aravanopoulos 2010). In another survey (Dini-Papanastasi 2004), 13 clones from this variety were selected because of their outstanding growth abilities, green foliage retention in autumn and smaller thorns. In Dini-Papanastasi & Papachristou (1999), clones ‘B-A(13)’ and ‘B-6A(8)’ performed best in terms of forage production.

There is no record of when breeding efforts began in South Korea. According to Lee et al. (2007), 63 clones were selected, and the selection from Ganghwa had the highest nectar production capacity.

Fig. 3 - A 3-year-old, new black locust clone (‘PL251’) in an Eastern Hungarian experimental plantation (photo: Tamás Ábri, 2023)

Molecular marker techniques supporting black locust breeding

Finally, the most significant molecular genetic studies concerning black locust breeding are summarised as these techniques have become increasingly widespread and accessible.

Applying highly variable microsatellite markers (SSRs, simple sequence repeats) is an effective tool for fingerprinting individuals and, subsequently, identifying different clones (Weising et al. 2005). Although several marker sets in black locust are already available for specific nuclear regions (Mishima et al. 2009, Lian & Hogetsu 2002), and EST-SSR markers developed from expressed sequences (Guo et al. 2017, Dong et al. 2019), only Chinese cultivars have been fully profiled (Dong et al. 2019). The mentioned EST markers can be recommended for future phenotype-genotype association studies because a putative linkage between a given characteristic and the genetic pattern is supposed for this marker type. SSR markers are also suitable for parentage analysis in directional crossbreeding (Sun et al. 2021) or population structure analysis (Yaegashi et al. 2020, Guo et al. 2022a). Another option for broad-scale population genetic studies and deeper genetic profiling of different genotypes can be the application of SNPs (single-nucleotide polymorphisms). However, only one marker set of 377 SNP markers – derived from restriction-site associated DNA sequencing (RADseq) by Verdu et al. (2016) – is currently available. No case studies using these markers have been published so far. Former studies applying isozymes (Liesebach et al. 2004) and chloroplast DNA markers (Liesebach & Schneck 2012) deserve mention because these marker types can be appropriate for detecting geographic patterns and distinguishing between provenances. However, the studies observed no clear geographic structure in the Hungarian sites due to the extensive artificial planting that generated a homogeneity among black locust stands compared with the analysed native range and the German stands. On the other hand, the cpDNA study revealed that the German lineage with straight stem form type is characterised by one specific cpDNA haplotype and putatively originated from the western part of the natural range in the USA (Central Highlands). Most previously mentioned markers with detailed molecular lab methodology have been summarised in a single manual for the genetic analysis of non-native forest tree species in Europe (Neophytou & Konnert 2018). Furthermore, the whole chloroplast genome data of five *Robinia* species have already become available, facilitating more detailed chloroplast-based analyses in the future (Yu et al. 2019).

Conclusions

Black locust was the first forest tree species introduced from North America and acclimated to Europe. It has numerous beneficial traits, including fast growth, nitrogen fixation, and excellent sprouting capacity. Furthermore, it is a frequent and abundant seed producer, has a relatively high yield potential, and produces durable, high-quality wood, making it optimal for industrial wood plantations. Although native to North America, black locust is naturalised and widely planted in areas ranging from temperate to subtropical. Nowadays, it also has the potential to play a significant role in mitigating negative climate change impacts due to its high site tolerance in semi-arid and arid regions. However, future research still has some gaps to fill. The most notable is invasiveness, which is a severe drawback in the use of black locust in Europe; breeding fully sterile clones or clones with lower root suckering capacity are potential breeding objectives that address invasiveness. Breeding activity is also closely related to the development of plantation technology. Improved growing technologies can mitigate the negative effects of black locust by providing strict control of its spatial distribution. This study provided a review based on research on species breeding and improvement to address the increasing interest in black locust growing technology in many countries.

Breeding efforts have taken several paths; the most evident is improving wood products for the wood industry; however, biofuel or honey production are also mainstream goals of black locust breeding. Appropriate cultivar selection and different tree plantation types should be considered for these varied purposes. Therefore, breeding activity is closely related to the plantation technology development of specialized fields. Conducting future clonal tests and comparative field trials is also necessary to determine the most suitable varieties for industrial tree plantations, agroforestry purposes or land remediation. Finally, in addition to field selection, several sophisticated breeding techniques and promising molecular marker tools can also be recommended for future application in forest tree improvement.

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Supplementary Material

Tab. S1 - Hungarian state-approved cultivars and candidate cultivars, according to the National Food Chain Safety Office of Hungary.

Link: Abri_4254@suppl001.pdf

