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Assessment of Aggressiveness of *Ganoderma resinaceum* (Boud.) Pathogenesis and Influence on Wood Decomposition of Pedunculate Oak (*Quercus robur* L.)

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ABSTRACT
Ganoderma resinaceum, which belongs to the *Ganodermataceae* family, is a fungus that is rare in Poland, and occurs mainly in green areas. In the light of the lack of literature reports concerning the degree of aggressiveness of the fungus in relation to the host and the decomposition rate of wood, we carried out an in-depth study of two trees on a new, previously unlisted site in Poland. We performed multilevel instrumental studies with the use of an acoustic tomograph and a resistograph in order to establish the degree of decomposition of the wood tissue of pedunculate oaks, combined with a visual assessment conducted using the VTA method.

Keywords: rare fungi, dendrology.

INTRODUCTION

In Poland, the *Ganodermataceae* family is represented by 6 species. The most common one in the country is undoubtedly *Ganoderma applanatum* – a cosmopolitan species that grows within the wood of living and dead trees. The pathogens belonging to this family form fruiting bodies attached laterally to the substrate with corky or wood flesh, with the exception of *G. carnosum* and *G. lucidum*, which form fruiting bodies on their stems. The surface of the fruiting bodies is most often covered with a resinous, shiny skin [Mańka 1998]. The spore print of *Ganodermataceae* is brownish with a shade that resembles cocoa. All species from the family cause a white uniform rot of wood, which is characterized by the simultaneous decomposition of all the components of the wood (cellulose, lignin and hemicellulose).

The wood dries up, shrinks and crumbles into fibrous fragments [Łakomy and Kwaśna, 2015]. In fact, several species from this family are very rare in Poland. According to the "Red List of Plants and Fungi of Poland" [Wojewoda and Ławrynowicz, 2006], *G. carnosum* is an endangered species, while *G. pfeifferi*, *G. resinaceum* and *G. lucidum* are rare, and potentially endangered. That said, only *G. lucidum* is covered by partial protection.

Due to the secretion of resin-like drops by the punctured hymenophore, *G. resinaceum* was treated as a subspecies of *G. lucidum*. It is rarely recorded in Poland; its natural hosts in Europe include mainly oaks [Rayner and Boddy 1988, Mattheck et al., 2015], and much less often beeches [Deflorio et al., 2008], alders, willows and plane trees [Schwarze and Ferner, 2003]. Next to *G. pfeifferi*, *G. resinaceum* is reported as a lowland species. The fungus is usually a parasite, but after the death of the host, it can function as a saprotroph [Mattheck et al. 2015, Deflorio et al. 2008]. The GRAJ register of protected Fungi lists the species only at two sites in Poland: in Kraków and Poznań [Snowarski 2020]. Both sites are related to green areas rather than forest stands, which is also consistent with the research of Beck et al. [2018], who indicate the presence of the fungus in parks and gardens, and in warmer regions, also in forests. The observations of Sokół et al. [1986] and Wojewoda [1999] also confirm the occurrence of the species in Silesia. The next site of the fungus was found during specialist tree research conducted in December 2019 in Warsaw at Puławska Street on two specimens of pedunculate oaks aged 50–60 years. Trees with fruiting bodies grew in line in the vicinity of a very busy street and intensive housing development. The fruiting bodies found were located in the butt-end, practically at the contact point of the trunks with the ground. The analysis is similar to the previous findings of the species in Poland [Snowarski, 2020], i.e., the pathogen prefers the base of tree trunks.

RESEARCH METHODOLOGY

a) Examination of the inside of trees using the PiCUS 3 Sonic Tomograph was carried out in four stages:
  - the geometry of the tree trunks' cross-section was determined by calculating the distance between the measuring points with the electrodes using the PiCUS electronic caliper. The tree geometry was determined on the basis of the triangulation method;
  - acoustic measurements were taken in planes perpendicular to the morphological axis of tree trunks by generating sound pulses, for which the time of movement of acoustic waves in the wood is recorded. The test levels were established starting from the level just above the ground (4 and 10 cm), subsequent test heights were set higher than the previous ones by 20 cm (Table 1);
  - the velocities of sounds propagating perpendicular to the trunk axis were calculated based on the travel time of acoustic waves and the previously measured distances between the electrodes;
  - cross sections of the tree trunks were generated as colored tomograms, creating the so-called map of tree density based on numerical data from acoustic measurements.

b) The condition of wood tissues was assessed using the IML-RESI PD500 resistograph:
  - the directions of measurements in planes perpendicular to the morphological axis of the trunks were determined, together with the inclination angle at heights coinciding with those of tomographic examinations (Figs. 6 and 8), and additionally;
  - two variables in the range of 28-90 cm were measured: the drilling resistance and the feed force simultaneously. The feed curve was reduced (considerably lower amplitudes) due to disturbances caused by additional resistance attributable to chips produced when drilling;
  - graphs of resistance curves based on measurement data were generated,

c) Assessment of the tree statics was performed on the basis of the VTA (*Visual Tree Assessment*) method, which consists in the analysis of visible symptoms that contribute to the loss or impairment of stability. The VTA method is based on the laws of biomechanics [Mattheck and Breloer 1994]. It takes into account a comprehensive view of a number of factors (biological and mechanical) that influence the behavior

Table 1. Acoustic tomograph examination results

Tree no.	Circumference at the height of 130 cm [cm]	Measurement no.	Measurement height [cm]	Decay level [%]	Healthy wood [%]	Initial decay [%]	Infection of peripheral tissues	Presence of cracks
1	128, 124	1	4	18	72	10	insignificant from the NE side	from the NW side
		2	24	16	74	10	insignificant from the NE and NW sides	from the NE side
		3	44	6	82	12	insignificant from the E and W sides	-
		4	64	-	100	-	-	-
2	219	1	10	15	72	13	significant from the N, NW and W sides	from the NW and S sides
		2	30	5	91	4	from the NW side	from the NE and NW sides
		3	50	-	100	-	-	-

Table 2. Assessment of the condition of trees

Scale	Assessment	
	Tree no. 1	Tree no. 2
Viability assessment according to Kasprzak [2005]	III	III
Health condition assessment according to Pacyniak and Smólski [1973]	2/3	2
Vitality assessment according to Roloff [1989]	2/3	2
Tree statics assessment (FRC classification)	C/CD	B/C

of statics. For the risk assessment, assessments used in park and street stands were applied.

d) Assessment of the risk class (supplementary for the VTA method) was conducted on the basis of the FRC (*Failure Risk Classification*) developed by ISA-SIA. The trees were classified into one of five decreasing trend classes. The classification was carried out after careful analysis of the health condition, shape and features of the tree structure.
e) Viability was assessed according to the Kasprzak scale [2005].
f) Health condition scale was assessed according to Pacyniak and Smólski [1973].
g) Vitality was assessed according to the Roloff scale [1989].
h) Identification of the fungus was confirmed based on the analysis of microscopic features (det. B. Gierczyk, Faculty of Chemistry, Adam Mickiewicz University in Poznań). The specimen was preserved in a private fungarium of the identifying person (collection no: BGF0004926).

RESULTS AND DISCUSSION

The trees grew in the green belt along Puławska Street (near the intersection with Kajakowa Street) in the vicinity of other trees (Fig. 11). There were communication routes (pavements, bicycle path, access road), as well as technical infrastructure in their vicinity (Fig. 12). The biologically active area was estimated at 85% in the case of tree no. 1 and approx. 50% for tree no. 2.

Tree no. 1 formed a crown at 1/3 of its height, which was built on two main structural limbs (Fig. 9). During examinations, the branch snag was found at an average level (Fig. 10). The tree trunk had two conductors, creating a U-shaped fork at a height of 1.1 m. In the thick-end from the NE side, there was a wound with profound decay and callus tissue and remains of fruiting body of *G. resinaceum* (Fig. 2). No evidence of flutes was found. Examination with an arborist probe revealed damage to the root system from the SE and SW sides.

Tree no. 2 had a crown at 1/3 of its height set on the main conductor, which split at half height into two branches with a U-shaped fork. The crown showed traces of past cuts, mostly scarred with wound tissue. The fruiting of the tree was poor. Branch and bough snag was found in the crown. The tree trunk was slightly sloped (Fig. 12) with healed traces of old cuts. No flutes were found. Examination with an arborist probe did not reveal any root rot.

The visual analysis of the crown condition shows a relationship between the occurrence of branch and bough snag and fungal infection. Additionally, low scores for vitality according to the Roloff scale [1989] show that the infestation with *G. resinaceum* is not without consequences for the physiological condition of trees.

The sizes of the largest fruiting bodies, which had a cap skin with a hymeniodermic structure, were at the level of 35–55 cm in diameter and were similar to the observations of Snowarski [2020], who indicated the size of the fruiting bodies in the range of 10–45 cm. The fruiting bodies were laterally attached to the substrate (trunks)

Fig. 1. Fresh fruiting bodies of *Ganoderma resinaceum* (Boud.) Pat., photo: K. Jankowski

Table 3. Resistograph test results

Tree no.	Circumference at the height of 130 cm [cm]	Measurement no.	Measurement direction	Measurement height [cm]	Peripheral tissue width [cm]	Decay range (depth) [cm]	Range of healthy wood [cm]	Structural changes within healthy wood	Cracks (depth) [cm]
1	128, 124	1	N-S	4	~6.5	>8	1.5-8	-	-
		2	N-S	24	~5.5	>7	1.5-6	-	-
		3	N-S	44	~7.5	10-33	>39	at the depth of 33-39 cm	-
		4	N-S	64	~6	8-9	2-6 9-47	insignificant	47.5
		5	NE-SW	28	~5	>6,5	1.5-6.5	insignificant	-
		6	NE-SW	50	~5.5	7-8.25 13-36	1.5-7 8.25-11 >36.5	-	-
2	219	1	N-S	10	~7.5	>9	1.5-9	-	-
		2	N-S	30	~2	>4	2-4	-	-
		3	N-S	50	~5	7-8	2-7> 19	at the depth of 11-19 cm	35.5
		4	N-S	70	~5	7-8.5	>8,5	-	-
		5	N-S	90	~5	7.5-8	2-7 >8	at the depth of 34-46 cm	-
		6	SW-NE	10	-	30-50	8-30	-	-
		7	SW-NE	40	~34	>36	2-36	-	-
		8	SW-NE	80	>2.5	-	>2.5	-	-

(Figs. 1 and 4); one of them was torn off and left in the vicinity of the tree. The fruiting bodies of the fungus were one-year-old, i.e., they developed in one growing season; they undergo destruction in the autumn and winter period. It must be stressed that the large size of the pathogen's fruiting body might indicate their perennial character, but in fact they are one-year-old specimens. In the next year, despite maintaining a reasonably uniform structure, they are dead and the pathogen begins to produce new fruiting bodies at the turn of IV/V which basically sprout without a stem, with only one layer of tubing and context.

The results of tomographic examinations showed the greatest surface decomposition changes at the height of fruiting bodies (18% and 15% of the trunk cross-sectional area). The propagation speed of sound waves was in the range of 830-900 m/s (tree no. 1) and 790-970 m/s (tree no. 2) and was lower (by 31-44%) than the sound velocity in healthy wood, amounting to 1400 m/s. The peripheral tissues in the case of tree no. 1 showed a slight degree of structural changes, in contrast to the tissues of tree no. 2, where the research indicated advanced decay within the fruiting body. Wood decay did not exceed 64 cm from the ground level (no foci of structural changes were found) (Figure 1).

Examinations using the resistograph confirmed the results of tomography in the case of tree no. 1, both in terms of the extent of distribution and thickness of peripheral tissues. On the other hand, we found the presence of peripheral tissues in tree no. 2 from the fruiting body side (Table 3), which was not demonstrated by the tomographic examination. Nevertheless, in both cases the greatest extent of wood decomposition was visible within the

Fig. 2. Healed necrosis on tree trunk no. 1, where the Ganoderma fruiting body was forming on the surface, photo: M. Mincel

lowest test levels and decreased with increasing height of the drilling operations.

The results also showed that with the increasing distance between the measurements on the trunks and the site where the fruiting bodies were formed, wood decomposition decreased both in terms of the surface and the degree of advancement. This points to a relationship between the vertical extent of wood decay and the site of formation of the fruiting bodies; it is highly likely that the greatest decomposition of wood will occur in the vicinity of the site where the fruiting bodies are formed. In both cases, the decay covered similar heights of trunks from the ground surface (not exceeding 65 cm). The decay of the wood tissue in the studied pedunculate oaks shows that it is a fungus that decomposes both the whitish part of the wood (to a lesser extent) as well as the heartwood (Figs. 5 and 7), which is also confirmed by the research of Watson and Green [2011]. On this basis, it is therefore concluded that the fungus is clearly more a parasite than a saprotroph, which is also

Fig. 3. Tomograph examination of tree no. 1, the butt-end on the right side has a visible trace of a fruiting body, photo: M. Mincel

Fig. 4. Butt-end of trunk in tree no. 2 during a CT scan with a visible fruiting body, photo: M. Mincel

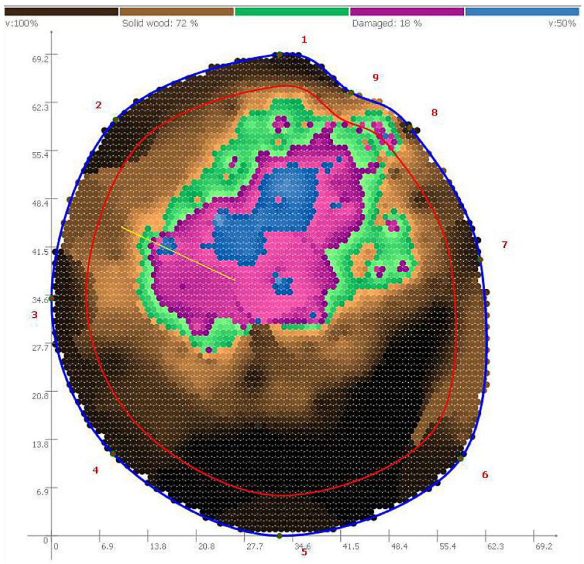

Fig. 5. Tomogram - tree no. 1, examination at a height of 4 cm

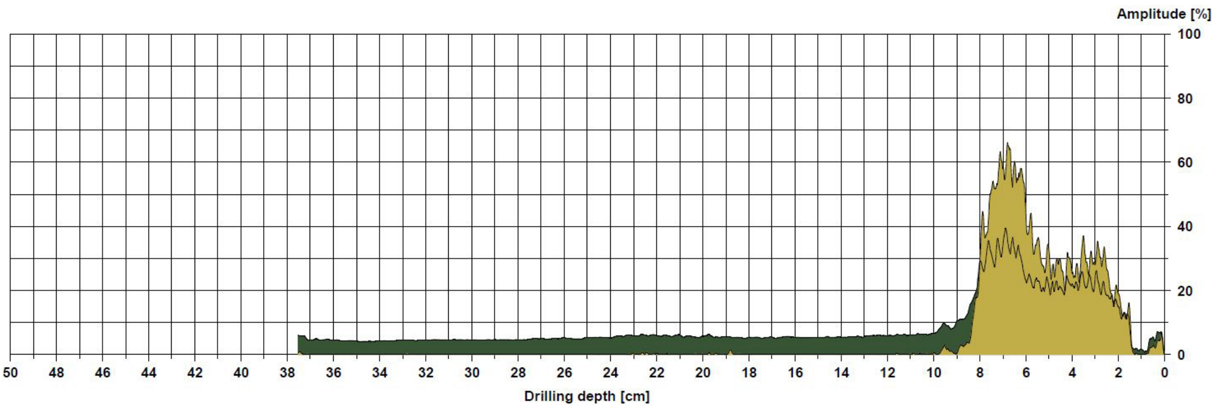

Fig. 6. Dendrogram - tree no. 1, examination at a height of 4 cm

confirmed by the research of Beck et al. [2018]. A critical view should be taken of the observations of Lonsdale [1999] and Beck et al. [2018], who notice the morphological similarity between *G. resinaceum* and *G. lucidum*. In reality, the appearance of the fruiting bodies produced by the fungus remains very similar to *G. pfeifferi*, and the distinction between these species is practically possible only on the basis of microscopic examination. As concluded by Schwarze and Ferner [2003], the resin layer of the *G. resinaceum* fruiting body melts when heated by the flame of a match, which helps to distinguish between the two species. An additional distinctive feature of this species in the field is - due to the hymeniodermic structure of the peel of the fruiting body – easy indentation with a finger. In turn, *G. lucidum* produces fruiting bodies consisting of a kidney-shaped and flat cap and a shaft - unlike *G. resinaceum* and *G. pfeifferi*, which do not produce stalks at all, thus notes regarding the morphological similarities of the fruiting bodies of *G. resinaceum* and *G. lucidum* are unjustified. The pathogen should be considered as the fungus most willingly located in the butt-end of trees and the wood decay found in this trunk zone

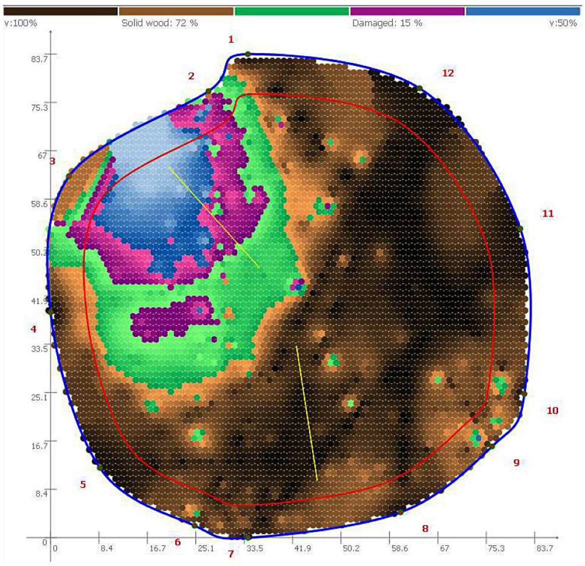

Fig. 7. Tomogram - tree no. 2, examination at a height of 10 cm

Fig. 9. Surroundings of tree no. 1 and the crown, photo: M. Mincel

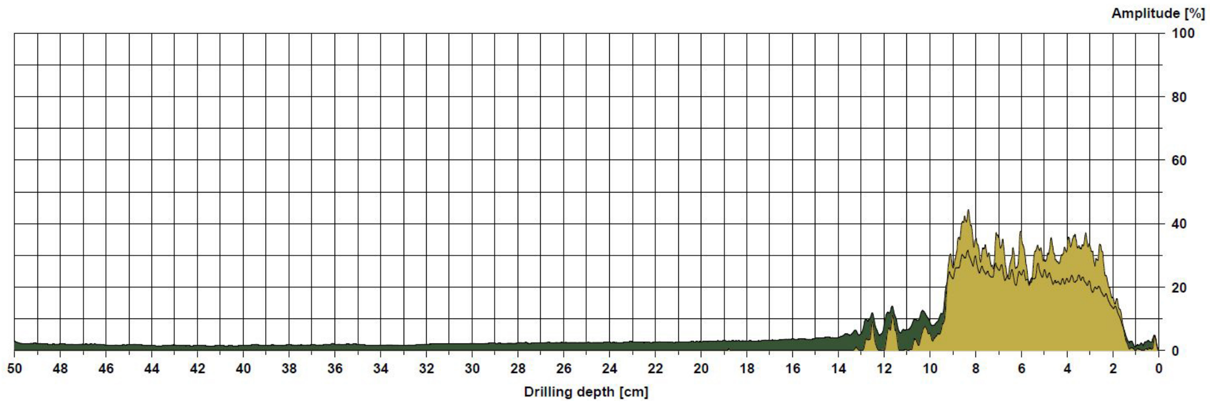

Fig. 8. Dendrogram - tree no. 2, examination at a height of 10 cm

Fig. 10. Surroundings of tree no.1 and the crown, photo M. Mincel

was the greatest. The highest level of wood decay, amounting to 18% of the trunk cross-section, was practically at the contact point between the trunk and the ground (Table 1) in the case of tree no. 1. The fungus operates mainly in the lowest part of the trunk; practically from a height of 30 cm above ground level, the level of wood decay did not exceed 6%. Similar results were obtained by Watson and Green [2011] and Rayner and Boddy [1998], who indicate that the fungus-induced decomposition of wood is limited to the butt-end and flutes. According to Schwarze and Ferner [2003], the location of the wood decay zone may depend on the host species and in the case of oaks (*Quercus spp.*), it is most often limited to the butt-end, which is also confirmed by this study (Table 1). In turn, in the case of *Platanus* sp., the wood decay zone can also cover the upper parts of the tree trunk [Schwarze & Ferner, 2003]. In the examined oak trees in Warsaw, the pathogen was infected through wounds located in the butt-end of the trunk; the presence of wounds is indicated by traces of scarring necroses (Fig. 2). Furthermore, the nature of the spread of wood decay indicates wound infections on the trunk (non-root).

Fig. 11. Surroundings of tree no. 2, photo: M. Mincel

Fig. 12. Surroundings of tree no. 2, photo: M. Mincel

CONCLUSIONS

1. *G. resinaceum* is a parasite that attacks living trees (most often pedunculate oaks), which does not demonstrate a high degree of aggressiveness. The decomposition of wood caused by fungus is not rapid; the development of rot slowed down by phenolic barriers does not cause sudden death of pedunculate oaks.
2. It is not justified to select pathogen-infected trees for felling solely on the basis of the presence of fruiting bodies – there is a need for in-depth diagnostic analyses of the inside of tree trunks.
3. *G. resinaceum* should be included in the group of pathogens associated with green areas; it is practically non-existent in forest stands. The pathogen may exist not only in typical old trees with a fragile physiological condition, but also in younger specimens aged 40–60 years.
4. The pathogen prefers the butt-end parts of tree trunks, most often at the junction of the trunk with the ground, which weakens the oldest part of the tree trunk causing mainly heartwood decomposition.
5. Due to the fact that the fungus is rare, when it is necessary to cut trees, it is advisable to preserve biodiversity, leaving the so-called monadnocks several meters long (high) to extend the period of natural propagation of the fungus.
6. There are grounds for placing a fungus species under legal protection due to the significantly limited area of its occurrence in Poland.

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