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PESTS AND DISEASES AFFECTING EUCALYPTS IN PORTUGAL: CURRENT SITUATION AND FUTURE PROSPECTS

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SUMMARY

Several pests and pathogens cause damage to eucalypts (*Eucalyptus* spp.) in Portugal. Most of these organisms are insects and fungi native to Australia, the region of origin of eucalypts, with which these species coevolved. The number of pests and diseases affecting eucalypts has been increasing worldwide in the last five decades, due to the growing circulation of people and goods. Fourteen pests and several dozens of pathogens have already been found in Portugal, most of them in the last twenty years. Economic losses caused by biotic agents may be important, both in forest plantations and in nurseries. To reduce their impact, control methods must be developed and employed. The main control methods are: i) classical biological control, in which specific natural enemies from Australia are imported and introduced into Portugal; ii) selecting and planting resistant or tolerant eucalypts; and iii) applying pesticides. This work aims to review the status of the pests and diseases affecting eucalypts in Portugal, their impacts, and the success of the management strategies that have been employed. Because new pests and diseases are expected to arrive in the coming years, future challenges are also discussed.

Keywords: Biological control, *Eucalyptus globulus*, genetic improvement, integrated pest management, invasive species.

INTRODUCTION

Eucalypts that established early outside their native range have typically benefited from a pest-free environment. However, over time, several Australian insects and microorganisms that attack eucalypts reached the regions where these trees are commercially planted [1-3]. For example, in 2016, there were 42 Australian insects affecting eucalypts outside their native range [3].

The pathways leading to the introduction of pests and diseases are unknown in most cases, but circulation of people and trade of wood products, live plant material, and other commodities have certainly contributed to their spread [1,3]. Many of these exotic species first established in a single region outside Australia, where they proliferated, followed by new introductions of these species into other regions. This is the case of eucalypt pests and diseases present in Portugal, which were not introduced directly from Australia, but originated in countries in South America, Africa, or other European countries.

Although the main pests and diseases of eucalypts originate in Australia, some insects and fungi that occur naturally in areas where eucalypts were introduced are also relevant problems [1,4]. Shifting of native pest species onto eucalypts has occurred mainly in Africa, Asia, and South America. These species are generally either highly polyphagous, i.e., they can attack very different plants, or they already have native plants of the Myrtaceae family, to which *Eucalyptus* belongs, as natural hosts [1,2]. However, in Portugal, few native organisms affect eucalypts, and the main pests and diseases are from Australia.

This work aims to review the status of the pests and diseases affecting eucalypts in Portugal, particularly *Eucalyptus globulus*, the species most widely planted, their impacts, and the success of the management strategies that have been employed. Because new pests and diseases are expected to arrive in the coming years, future challenges are also discussed.

PESTS AND DISEASES IN PORTUGAL, THEIR IMPACT AND ECONOMIC IMPORTANCE

Fourteen phytophagous arthropods specific to eucalypts are currently present in Portugal, namely thirteen insects and one mite. Regarding diseases, the most important are caused by fungi and by oomycetes (Table 1).

Table 1. Pests and diseases of *Eucalyptus* present in Portugal.

	Scientific name	Common name	Type of feeding	Main damage	Year of detection
Pests	*Gonipterus platensis*	Snout beetle	Defoliator	Stunted growth	1995
	Trachymela sloanei	Tortoise beetle	Defoliator	Stunted growth	2019
	Phoracantha semipunctata	Longhorned borer	Wood borer	Tree death	1981
	Phoracantha recurva	Longhorned borer	Wood borer	Tree death	2001
	Thaumastocoris peregrinus	Bronze bug	Sap-sucking	Stunted growth	2012
	Ctenarytaina spatulata	Eucalyptus psyllid	Sap-sucking	Stunted growth	2002
	Ctenarytaina eucalypti	Blue gum psyllid	Sap-sucking	Stunted growth	1970
	Glycaspis brimblecombei	Red gum lerp psyllid	Sap-sucking	Stunted growth	2008
	Blastopsylla occidentalis	Eucalyptus shoot psyllid	Sap-sucking	Not causing damage	2010
	Rhombacus eucalypti	Mite	Sap-sucking	Not causing damage	2005
	Leptocybe invasa	Gall wasp	Gall maker	Stunted growth	2003
	Ophelimus maskelli	Gall wasp	Gall maker	Stunted growth	2006
	Ophelimus mediterraneus	Gall wasp	Gall maker	Stunted growth	2012
	Epichrysocharis burwelli	Gall wasp	Gall maker	Not causing damage	2015
Diseases	*Teratosphaeria* spp. *Mycosphaerella* spp.	Leaf spot disease		Stunted growth	1881[1]
	Botrytis cinerea	Grey mould		Stunted growth in nurseries	Unknown
	Quambalaria eucalypti	Quambalaria		Stunted growth in nurseries	2010
	Neopestalotiopsis spp.	Neopestalotiopsis		Plant death in nurseries	2012
	Neofusicoccum spp.	Stem canker		Tree death	Unknown
	Teratosphaeria gauchensis				2006
	Phytophthora spp.	Dieback disease		Tree death	1838[2]

[1] *Teratosphaeria* (=*Mycosphaerella*) *molleriana* was the first species detected in Portugal, in 1881, but several other species of *Mycosphaerella* and *Teratosphaeria* were reported in eucalypts since the 1990's [5,6]. Severe defoliation caused by this species-complex has been reported only since 1998.

[2] The species *Phytophthora cinnamomi* causes disease in a wide range of hosts, including eucalypts. This species was first recorded from Portugal in 1838, in chestnuts [7]. Since 2010, five *Phytophthora* species were recorded in eucalypts [8,9]. Until 2020, no severe problems related to *Phytophthora* spp. were recorded on eucalypts.

Not all the species of insects and microorganisms attacking eucalypts are economically relevant. The most important ones severely affect the roots, leaves, branches, or stems, and may have negative effects on plant vigour, development, and survival. In Portugal, the eucalyptus snout beetle, *Gonipterus platensis*, the wood borers from the genus *Phoracantha*, and the bronze bug, *Thaumastocoris peregrinus*, have been the most relevant pests. Recently, the tortoise beetle *Trachymela sloanei* has also started causing important damage to eucalypts planted in the South of the country.

The main diseases occurring in Portuguese eucalypt plantations include leaf spot disease and cankers, which are caused respectively by fungi from the *Teratosphaeria/ Mycosphaerella* and *Neofusicoccum/ Teratosphaeria gauchensis* groups [10-13]. In the last three years, tree mortality due to *Phytophthora* spp. has been increasing, and new species have been detected [8,9]. While the previous diseases are particularly important in plantations, others are more common and problematic in plant nurseries, such as the one associated to *Neopestalotiopsis* spp. [14].

In plantations for wood production, the most important impact of pests and diseases is the loss in wood volume growth. For example, in the case of the eucalyptus snout beetle in Portugal, it is estimated that the insect causes losses of around 1 million m^3 of wood per year [15]. In addition to the effect of pests and diseases on wood production, there are often several impacts in terms of other services generated by the ecosystems. The activity of these biotic agents can negatively affect the production of other goods, such as honey or foliage used to extract essential oils, regulatory and supportive functions (e.g., carbon sequestration and water retention), and cultural and recreational functions [16]. These impacts may, in turn, have a relevant socio-economic dimension, as they translate into direct economic losses for forest owners and for industries related to the forestry sector, into loss of jobs, and into the need to increase wood imports [15,16].

CONTROL METHODS

The most used methods to reduce losses caused by pests and diseases affecting eucalypts include: i) classical biological control, which consists of importing and releasing specific natural enemies, usually other insects that feed on the pests; ii) selection and planting of eucalypt varieties that are less susceptible to the activity of harmful biotic agents; and iii) the use of plant protection products, such as insecticides and fungicides (Table 2). However, on a smaller scale, other methods may also be used. For example, for the control of the eucalyptus longhorned borers, *Phoracantha* spp., log traps are employed to capture insect adults. Also, cutting and removing attacked trees allows to eliminate the larvae and pupae developing inside the trunks.

Classical biological control is a particularly useful strategy to reduce the impact of exotic pests that are not controlled by existing natural enemies in the invaded area [17,18]. The natural enemies used for biological control are often parasitoids (i.e., insects that develop inside the eggs or the larvae of the pest and kill the host) specific to the insect pests and with the same geographic origin. Although most insects used as biological control agents worldwide did not have any undesirable impacts, the release of exotic natural enemies may entail risks, namely that of affecting populations of native insects. Thus, it is essential that prior to the introduction of a biological control agent in a new region, a careful and exhaustive assessment of the potential risks and benefits is carried out. Taking these precautions, biological control is an effective, safe, economical, and long-lasting solution [18-23].

In Portugal, the biological control program against the eucalyptus snout beetle stands out. This program began in 1997, using the Australian egg parasitoid *Anaphes nitens* as biological control agent. Although it did not allow the pest to be controlled throughout all the territory, it contributed to substantially reduce its impact, with a high economic return [15]. Later, in 2012, another egg parasitoid, *Anaphes inexpectatus*, was introduced in Portugal, and in 2023, the larval parasitoid *Anagonia lasiophthalma* started to be released [24-27].

Susceptibility of eucalypts to phytophagous insects and pathogens has been studied and explored to reduce their damage. In the case of diseases, planting less susceptible eucalypts (species, hybrids, provenances, families, or clones) is the most relevant measure for controlling them in the field. For example, when outbreaks of *Phytophthora* spp. started to occur in Portugal, in 2020, the most susceptible *E. globulus* commercial clones were rapidly replaced by resistant *E. globulus* clones. The eucalyptus snout beetle is a good example of a pest to which the susceptibility of different species of *Eucalyptus* has been investigated and used as a mitigation measure. In countries where the eucalyptus snout beetle is present, *E. globulus* is consistently considered one of the most susceptible hosts, with other *Eucalyptus* species identified as more resistant or tolerant [28-31]. The species *Eucalyptus nitens*, less attacked by the insect, has been widely planted as an alternative to *E. globulus*, especially in northern regions of Spain where severe defoliation by *G. platensis* repeatedly occurs [32]. However, *E. nitens* has important disadvantages when compared to *E. globulus*, namely lower wood quality for the pulp and paper industry [33] and poor coppicing ability [34]. In Portuguese regions with high risk of attack by *G. platensis*, a commercial hybrid clone (*E. saligna* x *E. rudis*) that is significantly less attacked than *E. globulus* and is well adapted to those sites is commonly planted.

Table 2. Control methods used or in development against the pests and diseases of *Eucalyptus*, in Portugal.

	Scientific name	Control methods in use	Success of the control methods	Control methods under development
Pests	*Gonipterus platensis*	Biological control with the egg parasitoids *Anaphes nitens* and *A. inexpectatus*	Partially effective, low parasitism rates at high altitude	Release and monitoring of the larval parasitoid *Anagonia lasiophthalma* Selection and breeding of less susceptible eucalypts
		Use of less susceptible eucalypts	Effective	
		Chemical control with insecticides	Effective	
	Trachymela sloanei	Chemical control with insecticides	Effective	Import and evaluation of the egg parasitoid *Enoggera reticulata* Selection and breeding of less susceptible eucalypts
	Phoracantha semipunctata and *P. recurva*	Biological control with *Avetianella longoi*	Partially effective	Selection and breeding of less susceptible eucalypts Identification of semiochemicals for mass capture of adults
		Felling of dead trees	Partially effective	
		Log traps	Partially effective, mostly used for monitoring	
	Thaumastocoris peregrinus	Biological control with the egg parasitoid *Cleruchoides noackae*	Under evaluation	Selection and breeding of less susceptible eucalypts
		Chemical control with insecticides	Effective	
	Ctenarytaina spatulata	None		
	Ctenarytaina eucalypti	Biological control with the nymph parasitoid *Psyllaephagus pilosus*	Effective	
	Glycaspis brimblecombei	Biological control with the nymph parasitoid *Psyllaephagus bliteus*	Partially effective	
		Chemical control with insecticides	Partially effective	
	Blastopsylla occidentalis	Biological control with the nymph parasitoid *Psyllaephagous blastopsyllae*	Unknown	
	Rhombacus eucalypti	None		
	Leptocybe invasa	None		
	Ophelimus maskelli	Biological control with *Closterocerus chamaeleon*	Partially effective	
	Ophelimus mediterraneus	None		
	Epichrysocharis burwelli	None		
Diseases	*Teratosphaeria* spp. *Mycosphaerella* spp.	Use of less susceptible eucalypts	Partially effective	Selection and breeding of less susceptible eucalypts
		Chemical control with fungicides in nurseries	Effective	
	Botrytis cinerea	Chemical control with fungicides in nurseries	Effective	
	Quambalaria eucalypti	None		
	Neopestalotiopsis spp.	Use of less susceptible eucalypts	Effective	Selection and breeding of less susceptible eucalypts
		Chemical control with fungicides in nurseries	Partially effective	
	Neofusicoccum spp. *Teratosphaeria gauchensis*	None		
	Phytophthora spp.	Use of less susceptible eucalypts	Partially effective	Selection and breeding of less susceptible eucalypts
		Chemical control with fungicides	Partially effective	

The use of plant protection products is an effective and necessary method for controlling various pests and diseases. The application of fungicides, not generally used in plantations, is however quite effective in plant nurseries for the control of diseases, such as *Neopestalotiopsis* spp. and *Botrytis cinerea*. The insects *G. platensis* and *Trachymela sloanei* are examples of pests in Portugal whose control may require the application of insecticides [15]. However, the use of insecticides against eucalypt pests has been limited due to high application costs, legal restrictions, and to the effort to reduce the use of pesticides induced by forest management certification [3,35]. Additionally, insecticides generally present greater risks than other control methods, namely for human health, for domestic animals and for the environment, including effects on beneficial insects, such as pollinators and natural enemies of pests [36,37]. These risks imply the need to use insecticides judiciously, applying them only in the absence of alternatives, and complying with legislation and best practices (e.g. [38]).

These different control methods are generally used together and in a complementary way, with other indirect measures, such as silvicultural actions (e.g. fertilization or weed control), which contribute to improve the resilience of eucalypt plantations.

CHALLENGES AND PROSPECTS TO INTEGRATED PEST AND DISEASE MANAGEMENT

Effective methods for the control of harmful biotic agents must be available to assure the sustainability of eucalypt plantations. Legal, bureaucratic, or certification restrictions to the import and release of exotic natural enemies and to the use of pesticides, hinder the implementation of these control actions. Additionally, there may also be technical limitations, such as the difficulty to discover effective natural enemies and classifying them taxonomically, or in identifying varieties of eucalypts less affected by certain pests or diseases and not affected by others.

The need to guarantee the existence of effective control methods is particularly relevant in a context in which the number of pests and diseases associated with eucalypts outside Australia has been increasing rapidly. Furthermore, climate change may increase the harmfulness and economic importance of some insects and pathogens [39,40]. It is therefore expected that, in the future, there will be a greater number of pests and diseases, which will affect forest productivity and production costs, making the management of planted areas more complex. It is also foreseeable that some of the next introductions will be poorly studied or even unknown species, which will require resources for studying their biology and ecology, necessary to develop effective control strategies [3]. To face this threat, it is necessary to develop and implement procedures that reduce the dispersion of pests and diseases to new territories and also measures that effectively mitigate the impacts of those that have settled. It is expected that the expansion of eucalypt plantations that has taken place on several continents will promote greater circulation of eucalypts and woody materials globally, favouring the involuntary transport of pests and diseases. To this end, it is essential to reinforce the coordination of efforts, both nationally and internationally, with regard to the inspection and interception of infested material on arrival in the country, the early detection of new problems by installing sampling points in the most sensitive areas, and the monitoring of pests and diseases once installed in the territory (e.g. using remote detection and other technologies). It is also necessary to invest in research and development, namely in the development of rapid identification methods, in control measures (e.g. identification of natural enemies to be used in biological control programs) and in the identification and selection of resistant plants. Proper implementation of these measures will allow us to coexist with these invasive organisms, minimizing their economic losses.

REFERENCES

1. M. Wingfield, B. Slippers, B. Hurley, T. Coutinho, B. Wingfield, J. Roux, Eucalypt pests and diseases: growing threats to plantation productivity, *South For*, **70**: 139–144 (2008).

2. T.D. Paine, M.J. Steinbauer, S.A. Lawson, Native and Exotic Pests of Eucalyptus: A Worldwide Perspective, *Annu Rev Entomol*, **56**: 181–201 (2011).

3. B.P. Hurley, J.Garnas, M.J. Wingfield, M. Branco, D.M. Richardson, B. Slippers, Increasing numbers and intercontinental spread of invasive insects on eucalypts, *Biol Invasions*, **18**: 921–933 (2016).

4. A.C. Alfenas, A.A.V. Zauza, R.G. Mafia, T.F. Assis, Clonagem e Doenças do Eucalipto, Editora UFV, Viçosa, Brasil (2009).

5. P.W. Crous, M.J. Wingfield, *Colletogloeopsis*, a new coelomycete genus to accommodate anamorphs of two species of *Mycosphaerella* on *Eucalyptus*, *Can J Bot*, **75**: 667–674 (1997).

6. M. Silva, H. Machado, A.J.L. Phillips, *Mycosphaerella* species occurring on *Eucalyptus globulus* in Portugal, *Eur J Plant Pathol*, **125**: 125–433 (2009).

7. B.S. Crandal The distribution and significance of the chestnut root rot Phytophthoras, *P. cinnamomi* and *P. cambivora*, *Plant Dis Report*, **34**(6): 194–196 (1950).

8. E. Diogo, H. Machado, A. Reis, C. Valente, A.J.L. Phillips, H. Bragança, *Phytophthora alticola* and *Phytophthora cinnamomi* on *Eucalyptus globulus* in Portugal, *Eur J Plant Pathol*, **165**: 255–269 (2022).

9. C. Bregant, E. Batista, S. Hilário, B.T. Linaldeddu, A. Alves, First report of *Phytophthora hibernalis*, *P. multivora* and *P. niederhauserii* causing root rot and bleeding cankers on *Eucalyptus globulus* in Portugal, *New Dis Report*, **47**(2): e12171 (2023).

10. C. Barradas, A. Phillips, A. Correia, E. Diogo, H. Bragança, A. Alves, Diversity and potential impact of Botryosphaeriaceae species associated with *Eucalyptus globulus* plantations in Portugal, *Eur J Plant Pathol*, **146**: 245–257 (2016).

11. E. Batista, A. Lopes, A. Alves, Botryosphaeriaceae species on forest trees in Portugal: diversity, distribution and pathogenicity, *Eur J Plant Pathol*, **158**: 693–720 (2020).

12. M. Silva, C. Valente, L.O. Neves, H. Machado, Evaluation of *Mycosphaerella* impact on eucalypts plantations in Portugal, *Revista de Ciências Agrárias*, **31**(2):112–118 (2008).

13. M.R.C. Silva, E. Diogo, H. Bragança, H. Machado, A.J.L. Phillips,. *Teratosphaeria gauchensis* associated with trunk, stem and foliar lesions of *Eucalyptus globulus* in Portugal, *For Pathol*, **45**: 224–234 (2020).

14. E. Diogo, C.I. Gonçalves, A.C. Silva, C. Valente, H, Bragança, A.J.L. Philips, Five new species of *Neopestalotiopsis* associated with diseased *Eucalyptus* spp. in Portugal, *Mycol Prog*, **20**: 1441–1456 (2021).

15. C. Valente, C.I. Gonçalves, F. Monteiro, J. Gaspar, M. Silva, M. Sottomayor, M.R. Paiva, M. Branco, Economic outcome of classical biological control: a case study on the *Eucalyptus* snout beetle, *Gonipterus platensis*, and the parasitoid *Anaphes nitens*, *Ecol Econ*, **149**: 40–47 (2018).

16. S. Branco, N. Videira, M. Branco, M.R. Paiva, A review of invasive alien species impacts on eucalypt stands and citrus orchards ecosystem services: towards an integrated management approach, *J Environ Manag*, **149**: 17–26 (2015).

17. M. Wingfield, E. Brockerhoff, B. Wingfield, B. Slippers, Planted forest health: The need for a global strategy, *Science*, **349**: 832–836 (2015).

18. M. Kenis, B.P. Hurley, A.E. Hajek, M.J.W. Cock, Classical biological control of insect pests of trees: facts and figures, *Biol Invasions*, **19**: 3401–3417 (2017).

19. J. van Lenteren, J. Bale, F. Bigler, H. Hokkanen, A. Loomans, Assessing risks of releasing exotic biological control agents of arthropod pests, *Annu Rev Entomol*, **51**: 609–634 (2006).

20. B.I. Barratt, Assessing safety of biological control introductions, *CAB Rev Perspect Agric Vet Sci Nutr Nat Resour*, **6**: 1–12 (2011).

21. P. De Clercq, P.G. Mason, D. Babendreier, Benefits and risks of exotic biological control agents, *BioControl*, **56**: 681–698 (2011).

22. D. Simberloff, Risks of biological control for conservation purposes, *BioControl*, **57**: 263–276 (2012).

23. A.E. Hajek, B.P. Hurley, M. Kenis, J.R. Garnas, S.J. Bush, M.J. Wingfield, J.C. van Lenteren, M.J. Cock, Exotic biological control agents: A solution or contribution to arthropod invasions?, *Biol Invasions*, **18**: 953–969 (2016).

24. C. Valente, C. Afonso, C.I. Gonçalves, M.A. Alonso-Zarazaga, A.R. Reis, M. Branco, Environmental risk assessment of the egg parasitoid *Anaphes inexpectatus* for classical biological control of the *Eucalyptus* snout beetle, *Gonipterus platensis*, *BioControl*, **62**(4): 457–468 (2017a).

25. C. Valente, C.I. Gonçalves, A.R. Reis, M. Branco, Pre-selection and biological potential of the egg parasitoid *Anaphes inexpectatus* for the control of the *Eucalyptus* snout beetle, *Gonipterus platensis*, *J Pest Sci*, **90**: 911–923 (2017b).

26. C. Valente, C. Afonso, C.I. Gonçalves, M. Branco, Assessing the competitive interactions between two egg parasitoids of the *Eucalyptus* snout beetle, *Gonipterus platensis*, and their implications for biological control, *Biol Control*, **130**: 80–87 (2019).

27. C.I. Gonçalves, C. Valente, C. Afonso, C. Martins, A.R. Reis, M. Branco, New challenges on the journey to control an old pest: can a tachinid come to the rescue?, *The Tachinid Times*, **33**: 4-13 (2020).

28. L. Hanks, J. Millar, T. Paine, C. Campbell, Classical Biological Control of the Australian Weevil Gonipterus scutellatus (Coleoptera: Curculionidae) in California, *Environ Entomol*, **29**: 369–375 (2000).

29. A.C. Rivera, S.S. Carbone, The effect of three species of *Eucalyptus* on growth and fecundity of the *Eucalyptus* snout beetle (*Gonipterus scutellatus*). *Forestry*, **73**: 21–29 (2000).

30. D. Lanfranco, H. Dungey, Insect damage in Eucalyptus: A review of plantations in Chile, *Austral Ecol*, **26**: 477–481 (2001).

31. C.I. Gonçalves, L. Vilas-Boas, M. Branco, G.D. Rezende, C. Valente, Host susceptibility to Gonipterus platensis (Coleoptera: Curculionidae) of Eucalyptus species, *Ann For Sci*, **76**: 63 (2019).

32. C. Pérez-Cruzado, F. Muñoz-Sáez, F. Basurco, G. Riesco, R. Rodríguez-Soalleiro, Combining empirical models and the process-based model 3-PG to predict *Eucalyptus nitens* plantations growth in Spain, *For Ecol Manag*, **262**(6): 1067-1077 (2011).

33. R. Kibblewhite, B. Johnson, C. Shelbourne, Kraft pulp qualities of *Eucalyptus nitens*, *E. globulus*, and *E. maidenii*, at ages 8 and 11 years, *NZ J For Sci*, **30**(3): 447–457 (2000).

34. K. Little, G. Van den Berg, G. Fuller, Coppicing potential of *Eucalyptus nitens*: results from a field survey, *South Afr For J*, **193**(1): 31–38 (2002).

35. P.G. Lemes, J.C. Zanúncio, J.E. Serrão, S.A. Lawson, Forest Stewardship Council (FSC) pesticide policy and integrated pest management in certified tropical plantations, *Environ Sci Pollut Res*, **24**: 1283–1295 (2017).

36. D. Pimentel, H. Acqua, M. Biltonen, P. Rice, M. Silva, J. Nelson, V. Lipner, S. Giordano, A. Horowitz, M. D'amore, Environmental and Economic Costs of Pesticide Use, *BioScience*, **42**: 750–760 (1992).

37. S.E. Sexton, Z. Lei, D. Zilberman, The Economics of Pesticides and Pest Control, *Int Rev Environ Resour Econ*, **1**: 271–326 (2007).

38. ANIPLA, Manual de Boas Práticas para o uso seguro e sustentável dos produtos fitofarmacêuticos de âmbito profissional (2016).

39. B. Slippers, J. Stenlid, M.J. Wingfield, Emerging pathogens: fungal host jumps following anthropogenic introduction, *Trends Ecol Evol*, **20**(8): 420–421 (2005).

40. M.J. Wingfield, J. Roux, B. Slippers, B.P. Hurley, J. Garnas, A.A. Myburg, B.D. Wingfield, Established and new technologies reduce increasing pest and pathogen threats to Eucalypt plantations, *For Ecol Manag*, **301**: 35–42 (2013).