Diagnostics[1]
Diagnostic

Gymnosporangium spp. (non-European)

Specific scope

This standard describes a diagnostic protocol for *Gymnosporangium* spp.

Specific approval and amendment

Approved in 2006-09.

Introduction

The genus *Gymnosporangium* contains a number of species, of which five are pests recommended for regulation in the EPPO region (EPPO/CABI, 1997). The focus of this protocol is the diagnosis of these five species: *Gymnosporangium asiaticum*, *G. clavipes*, *G. globosum*, *G. juniperi-virginianae* and *G. yamadae*.

The above mentioned *Gymnosporangium* species require two different host plants in order to complete their life cycles (heteroecious). The main hosts include apple (*Malus pumila*), pear (*Pyrus* spp.), quince (*Cydonia oblonga*), and other rosaceous species, depending upon the species of fungus involved. On these hosts, aecia develop after dikaryotization of spermatia produced in spermogonia (pycnia). The aecia form aeciospores infecting the alternate host juniper (*Juniperus* spp.). During the winter the fungus survives as mycelium on juniper, in spring on juniper telia with teliospores are formed. The basidiospores released by the germinated teliospores infect rosaceous species. Both the aeciospores and the basidiospores are airborne and can be spread over large distances.

Identity

Name: *Gymnosporangium asiaticum* Miyabe ex G. Yamada
Synonyms: *Gymnosporangium haraeanum* Syd. and P. Syd., *Gymnosporangium chinense* Long, *Gymnosporangium koreaense* H.S. Jacks. and *Gymnosporangium spiniferum* Syd. & P. Syd.
Anamorph: *Roestelia koreaensis* P. Henn.
Taxonomic position: Fungi: Basidiomycetes: Uredinales
EPPO computer code: GYMNAS
Phytosanitary categorization: I/A1 – as *Gymnosporangium* spp. (non-European).

Name: *Gymnosporangium clavipes* (Cooke & Peck) Cooke & Peck
Synonyms: *Gymnosporangium germinale* F. Kern and *Podisoma gymnosporangium-clavipes* Cooke & Peck
Anamorph: *Caeoma germinale* Schwein. and *Roestelia aurantiaca* Peck
Taxonomic position: Fungi: Basidiomycetes: Uredinales
EPPO computer code: GYMNCL
Phytosanitary categorization: I/A1 – as *Gymnosporangium* spp. (non-European).

Name: *Gymnosporangium globosum* (Farl.) Farl.
Synonyms: *Gymnosporangium fuscum* var. *globosum* Farl.
Anamorph: not known
Taxonomic position: Fungi: Basidiomycetes: Uredinales
EPPO computer code: GYMNGL
Phytosanitary categorization: I/A1 – as *Gymnosporangium* spp. (non-European).

Name: *Gymnosporangium juniperi-virginianae* Schwein.
Synonyms: *Gymnosporangium macropus* Link and *Gymnosporangium virginianum* Spreng.
Anamorph: *Aecidium pyrolatum* Schwein. and *Roestelia pyrata* Thaxt.
Taxonomic position: Fungi: Basidiomycetes: Uredinales
EPPO computer code: GYMNJV
Phytosanitary categorization: I/A1 – as *Gymnosporangium* spp. (non-European).

Name: *Gymnosporangium yamadae* Miyabe ex G. Yamada
Synonyms: none
Anamorph: not known
Taxonomic position: Fungi: Basidiomycetes: Uredinales
EPPO computer code: GYMNYA
Phytosanitary categorization: I/A1 – as *Gymnosporangium* spp. (non-European).

[1]The figures in this standard marked 'Web Fig.' are published on the EPPO Website www.eppo.org.

Detection

G. asiaticum causes **Japanese pear rust** on *Pyrus pyrifolia* (Japanese pear), and may infect other Asian pear species, *Pyrus communis* (European pear), *Cydonia oblonga* (quince) and other rosaceous species on which pycnia and aecia are produced. Aecia mature within a month after infection. In northern Japan, aeciospores infect the alternate hosts, *Juniperus chinensis* and *J. procumbus* in June and July causing swellings. The alternate hosts are not native to Europe, but widely grown as an ornamental tree or kept as an indoor bonsai plant. On Juniper, telia are produced in the following spring. The fungus may survive for many years in infected *J. chinensis* twigs, producing telia every year. The fungus has been reported in Canada, the USA, China, Hong Kong, Japan, Korea, Russia (Far East) and Taiwan.

G. clavipes causes **Quince rust**, also called **Cedar-quince rust**, which is an important disease of *Malus pumila* (apple) in North America. The fungus infects fruit but not leaves of apple, and both leaves and fruit of *Cydonia oblonga* (quince), *Crataegus* spp. (hawthorn) and other rosaceous species. It also infects pear, but does not cause a serious problem. In autumn, aeciospores infect young stems of *Juniperus communis* and *J. virginiana* producing galls, from which telial horns emerge under wet conditions in the following spring. The galls are perennial and may produce telia for 20 years. The fungus has been reported in Canada, Mexico, the USA and Guatemala.

G. globosum causes **American hawthorn rust**, also called **Cedar hawthorn rust**, and infects leaves of *Crataegus* spp. (hawthorn), but also leaves of *Malus pumila* (apple), *Pyrus* spp. (pear) and other rosaceous species in eastern North America. It rarely infects fruits and is a minor disease compared with cedar apple rust (see below) and quince rust. However, *G. globosum* can cause severe infections on *Crataegus* seedlings in nurseries. Its alternate host is *Juniperus virginiana*, which is an important timber and amenity tree in North America. Infection on *J. virginiana* causes galls. After germination of aeciospores and subsequent infection, an overwintering latent mycelium is produced on *J. virginiana* which can stay viable for more than one year. In spring, the telia produce basidiospores which infect rosaceous hosts again. The fungus has been reported in Canada, Mexico and the USA.

G. juniperi-virginianae causes **Cedar apple rust** on *Malus pumila* (apple) and other *Malus* spp. Apple is an important crop in the EPPO region. On apple, aecia and pycnia are produced on the leaves. The galls on the alternate host *J. virginiana* are annual, producing only one batch of telia. The fungus has been reported in Canada and the USA.

G. yamadae causes **Japanese apple rust**. It occurs in most apple-growing regions of Japan and causes damage by defoliation. Its morphology and disease cycle most closely resemble those of *G. globosum*. Pycnial and aecial lesions on apple leaves resemble those of cedar apple rust. Fruit infections are rare. The alternate host is *Juniperus chinensis*. The galls on *J. chinensis* produce telia for a period of one year only. The pathogen has been reported in Japan, Korea and China.

Host plants of *Gymnosporangium* spp.

G. asiaticicum
Aecial hosts: *Pyrus pyrifolia* (Japanese pear), other Asian pears, *P. communis* (European pear), *Cydonia oblonga* (quince), *Chaenomeles*, *Crataegus* spp. (hawthorn) and *Photinia*.
Telial hosts: *Juniperus chinensis*, *J. procumbus* (cedar).

G. clavipes
Aecial hosts: *Cydonia oblonga* (quince), *Malus pumila* (apple), *Amelanchier*, *Aronia*, *Chaenomeles*, *Crataegus* spp. (hawthorn), *Mespilus*, *Photinia*, *Cotoneaster*, *Sorbus* and *Pyrus communis* (European pear).
Telial hosts: *Juniperus virginiana*, *J. communis* and *J. communis alpine* (syn. *J. sibirica*).

G. globosum
Aecial hosts: *Crataegus* spp. (hawthorn), *Amelanchier*, *Malus*, *Pyrus*, *Sorbus*.
Telial hosts: *Juniperus virginiana*.

G. juniperi-viginianae
Aecial hosts: *Malus pumila* (apple) and other *Malus* spp.
Telial hosts: *Juniperus virginiana* and other *Juniperus* spp.

G. yamadae
Aecial hosts: *Malus pumila* (apple) and other *Malus* spp.
Telial hosts: *Juniperus chinensis*.

Symptoms caused by different *Gymnosporangium* spp. on different hosts

Pyrus spp.

Pyrus pyrifolia.
G. asiaticum produces pycnia on the upper surface of the leaves and aecia on the lower surface on thickened brown spots in a dense group or ring opposite the pycnia (Web Fig. 1a). The aecia are white, long and tubular, becoming ruptured at the tip, about $3-6 \times 0.25$ mm with rusty-brown contents.

Malus spp.

Malus pumila.
G. clavipes infects fruits, but not leaves of apple. Pycnia and aecia are rarely developed on apple fruits and clear rust symptoms are often absent. On fruit, a dark green lesion occurs at the calyx end, causing distortion of the fruit. *G. clavipes* causes lesions on fruit which extends to the core, while *G. juniperi-virginianae* causes only superficial lesions on fruit (Web Fig. 2a).

G. juniperi-virginianae produces aecia and pycnia on the leaves. Small yellow-orange lesions appear on the upper surface of the leaves and petioles, in which the pycnia are formed in small groups of 1–3 mm diameter. Several weeks later, yellow-brown lesions appear on the undersurface, in which the aecia are formed. In this stage, leaves may show cupping and

curling. On susceptible cultivars, infection of *G. juniperi-virginianae* can result in defoliation. Sometimes, superficial brown necrotic lesions on apple fruits can be observed. Sometimes these lesions contains pycnia, but rarely aecia (Web Fig. 4a,b,c).

G. yamadae produces aecia and pycnia on the leaves. Pycnia occur on the upper side in small groups. Aecia, 3–8 mm high × 0.3–0.5 mm diameter, occur on the lower surface of leaves (Web Fig. 5a). On susceptible cultivars, *G. yamadae* can cause severe defoliation. Infections on fruits are rare.

Crataegus spp.

G. globosum produces pycnia and aecia on the leaves (Web Fig. 3a,b). Pycnia are on the upper side of the leaves in groups of 1–3 mm in diameter on brown spots. Pycnia are visible from late spring to early summer. Aecia are produced on the under side of the leaves in groups or rings of 2–5 mm diameter opposite of the pycnia. Aecia are cylindric-fusoid with pointed tip and lacerate sides, whitish or brownish, 1–4 mm high × 0.2–0.5 mm wide with rusty-brown contents. Aeciospores are produced inside tubular protective sheaths (peridia) on the lower side of the leaves. Aeciospores are released when the peridium ruptures. Infections on fruit are rare.

Cydonia oblonga

G. clavipes causes severe symptoms on fruit (Web Fig. 2a). Dark-green lesions appear at the calyx end, extending to the core, and resulting in fruit distortion. Clear signs of rust are not necessarily present on malformed fruit. *G. clavipes* can be distinguished from *G. juniperi-virginianae*, by fruit lesions which extend to the core of the fruit. Fruit lesions caused by *G. juniperi-virginianae* are only superficial.

Juniperus spp.

G. clavipes causes slight swellings on twigs and branches, from which telial horns emerge under wet conditions in the following spring (Web Fig. 2c). The telial horns are orange-brown, short (1–3 mm) and knobby.

Juniperus chinensis.

G. asiaticum produces telia on leaves and green stems. Telia are as small cushions of orange-brown spores, 1–3 mm in diameter (Web Fig. 1b).

G. yamadae causes globose stem galls on stems, 3–20 mm in diameter. Telia are formed on galls, are conical, chestnut-brown and 5 mm in diameter.

Juniperus virginiana.

G. globosum causes globose galls on stems, twigs and branches of 3–10 mm diameter (Web Fig. 3b) on which telia are formed. Telia are conial, 3–12 mm high × 1.3 mm wide and chestnut-brown of colour.

G. juniperi-virginianae causes golfball-size galls, 1–3 cm in diameter, on twigs and branches on which telia are formed (Web Fig. 4d,e,f). Telia are long cylindric tapered, 10–20 mm long × 1–2 mm wide and rusty-brown.

Identification

Identification of the *Gymnosporangium* species mentioned is based on host-pathogen relations and morphological characters on plant material. *Gymnosporangium* species are obligate and cannot be cultured on artificial media. So far, no information on molecular diagnosis has been reported.

Usually, identification can only be done on aeciospores produced on the rosaceous species. The morphology of teliospores can be characteristic but teliospores can only be observed on Juniper plants, which are not always available. When spores are absent on infected plant material, incubation in a humid chamber can induce spore production.

Tables 1 and 2 give an overview of the host plants and spore morphology of different *Gymnosporangium* spp. (Aldwinckle, 1990; Laundon, 1977).

Spore illustrations of the different *Gymnosporangium* spp. are presented in Web Figs 6, 7, 8, 9, 10, 11, 12 and 13 (Laundon, 1977).

The non-European *Gymnosporangium* species might be confused with the European *Gymnosporangium* species *G. fuscum* D.C., *G. clavariiforme* (Jacq.) D.C., *G. confusum* Plowr., *G. cornutum* Arthur ex F. Kern and *G. tremelloides* R. Hartig.

A brief description of the disease is given, followed by host plants per pathogen and detailed spore morphology in Table 1 (Aldwinckle, 1990; Laundon, 1977; Parmelee, 1978).

G. fuscum is the cause of **European pear rust**, which is the most important pear rust in Europe. Symptoms on leaves of *Pyrus communis* (pear) and other *Pyrus* spp. are similar to those of cedar apple rust (*G. juniperi-virginianae*) on apple, and young infected fruits may become mummified. *G. fuscum* is able to overwinter in infected pear tissue and to produce aecia for up to two successive seasons. Telia are produced on *Juniperus sabina*, *J. chinensis*, *J. virginiana* and other *Juniperus* spp. on fusiform swellings. The pathogen is widely distributed in Europe and extends to Asia and North Africa. It has been introduced in North America, Colombia and California.

G. clavariiforme causes **European hawthorn rust**. Aecia occur mainly on *Crataegus* spp. (hawthorn), but has also been recorded on *Pyrus communis* (pear), *Cydonia vulgaris* (quince), *Amelanchier*, *Aronia*, *Cotoneaster* and *Sorbus*. Aecia are formed on leaves, fruits and stems. On *Juniperus communis* and *J. oxycedrus* telia are formed on long fusiform swellings or cankers on branches, sometimes witches' brooms are present. The pathogen is widespread in Europe, Middle East, Asia, southern Canada and the USA.

G. confusum causes **Medlar rust** and is destructive on *Cydonia vulgaris* (European quince) and occasionally causes weak infections on pear. The fungus can destroy foliage of highly susceptible *Crataegus* spp. (hawthorns) and has also been recorded on *Chaenomeles* (Japanese quince), *Cotoneaster*, *Mespilus germanica* (medlar) and *Sorbus*. The disease causes little damage to the *sabina* junipers hosts *J. oxycedrus*, and *J. sabina*. The pathogen is widespread through Europe, extends into Asia and is also established in the USA (Sinclair *et al.*, 1987).

Table 1 Hosts and spore morphology of *Gymnosporangium* spp. (non-European)

	G. asiaticum	*G. clavipes*	*G. globosum*	*G. juniperi-virginianae*	*G. yamadae*
Aecial hosts					
Malus spp.	–	**H**	**H**	**H**	**H**
Pyrus spp.	**H**	**H**	**H**	–	–
Amelanchier spp.	–	H	H	–	–
Aronia spp.	–	**H**	–	–	–
Chaenomeles spp.	H	H	–	–	–
Cotoneaster spp.	–	**H**	–	–	–
Crataegus spp.	H	H	H	–	–
Cydonia spp.	H	H	–	–	–
Mespilus spp.	–	**H**	–	–	–
Photinia spp.	H	H	–	–	–
Sorbus spp.	–	H	H	–	–
Aecia					
Shape	Tubular, torn at tip	Tubular, torn from apex or lacerate at sides	Cylindric–fusoid, pointed tip and lacerate sides	Finely lacerate to base, strongly curved and woolly appearance	Tubular/Horn–shaped, finely lacerate in a network pattern
Size (mm)	**3–6 × 0.25**	2–3 × 04–0.5	1–4 × 0.2–0.5	1–2 long	3–8 × 0.3–0.5
Colour	White	White	Whitish/brownish	Whitish	Brownish
Colour contents	Rusty brown	Orange to white	Rusty brown	Reddish–brown	–
Aeciospores					
Size (µm)	17–25	**28–36**	15–23	20–28	17–28
Cell wall size (µm)	1.5–2.5	**2.5–4**	1.5–2	1.5–2.5	**2.5–3.5**
Colour	**Yellow**	Orange (contents)	Cinnamon	Cinnamon	Gold–yellow
Number of pores	6–8	**hided**	7–9	8–10	**hided**
Telial hosts					
Juniperus spp.	H	H	H	H	H
Telia					
Swellings/galls	No swellings	Slight swellings on twigs or branches	Globose galls, 3–10 mm diam.	Globoid/reniform galls, 1–3 cm diam.	Globose stem galls, 3–20 mm diameter
Telia shape	Small cushions	Hemispheric/cushionlike	Conic	Long cylindrical tapered	Conic
Telia size	1–3 mm diam.	1–3 mm diam.	**3–12 mm high** × 1.3 mm wide	**10–20 mm long** × 2 mm wide	5 mm in diam.
Colour	Red brown/chestnut brown	Orange–brown to cinnamon	Chestnut–brown	Rusty–brown	Chestnut–brown
Teliospores					
Number of cells	2 cells	2 cells	2 cells	2 cells	2 cells
Size (µm)	**32–47 × 15–25**	35–60 × 20–28	**35–40 × 17–24**	45–65 × 15–21	**32–45 × 15–24**
Colour	Gold–yellow to cinnamon	Yellowish	Gold–yellow	Yellow to golden	Gold to cinnamon
Number of pores per cell	2 pores, near septum	**1 pore**	2 pores, near septum	2 pores, near septum	2 pores, near septum

H = reported as host.

G. tremelloides causes **European apple rust** and infects mainly *Malus sylvestris* (apple) and *Sorbus*, but also other *Malus* spp. and *Cydonia vulgaris* (quince). On apple the fungus can cause severe defoliation and attack the fruit at the blossom end. The telial host is *Juniperis communis* and other species of the '*oxycedrus*' group. The fungus is widely distributed in Europe extends into North-west Africa, and also occurs in China and western North America.

G. cornutum causes **Mountain ash juniper rust** and infects *Malus* and *Sorbus*. *Juniperus communis* is the telial host. This fungus regularly occurs on the same trees and even on the same leaves of *Sorbus*. The fungus is widely reported in Europe, Asia (areas of Archangel to Kamchatka), western China, Japan and North America.

Besides the above mentioned *Gymnosporangium* species, some other non-European *Gymnosporangium* species have been reported (Aldwinckle, 1990). However, they are not considered as quarantine organisms for the EPPO region. These species, *G. kernianum* Bethel, *G. libocedri* (Henn.) F. Kern and *G. nelsoni* Arthur, are briefly described.

G. kernianum causes **Kern's pear rust** on pear and on its alternate hosts: *Juniperus utahensis*, *J. occidentalis* and *J. pachyphlea* in the western United States. Aecia are cylindrical and 2.0–2.5 mm high. Aeciospores, 21–32 µm in diameter, are cinnamon brown and globose (Laundon, 1977).

G. libocedri causes **Pacific coast pear rust** on European and Asian pears resulting in malformation and premature drop of fruits, a serious disease in the western United States. The

Table 2 Hosts and spore morphology of *Gymnosporangium* spp. (European)

	G. fuscum	*G. clavariiforme*	*G. confusum*	*G. tremelloides*	*G. cornutum*
Aecial hosts					
Malus spp.	–	–	–	**H**	**H**
Pyrus spp.	**H**	**H**	**H**	–	–
Amelanchier spp.	–	**H**	–	–	–
Aronia spp.	–	**H**	–	–	–
Chaenomeles spp.	–	–	**H**	–	–
Cotoneaster spp.	–	H	H	–	–
Crataegus spp.	–	H	H	–	–
Cydonia spp.	–	H	H	H	–
Mespilus spp.	–	–	**H**	–	–
Photinia spp.	–	–	–	–	–
Sorbus spp.	–	H	H	H	H
Aecia					
Shape	Balanoid shaped, pointed closed tip, finely lacerate at sides	Tubular, lacerate at base	Tubular, lacerate at base	Finely lacerate to base	Cylindrical, coarsely at apex or at sides
Size (mm)	**2–5 × 1–3**	0.7–1.5 × 0.3–0.5	1–2 × 0.2–0.3	0.5–1	–
Colour	–	Pale	Whitish	–	Pale brown
Colour contents	Rusty–brown	Cinnamon–brown	Pale to cinnamon–brown	Reddish–brown	–
Aeciospores					
Size (µm)	23–37	20–30	17–28	28–50	18–29 (–35) × 16–25
Cell wall size (µm)	**2.5–4**	2–3	2–3	**2–5**	1–2.5
Colour	Cinnamon	Golden to cinnamon	Hyaline to cinnamon	Cinnamon	Yellow–brown
Number of pores	7–8	9–11	**hided**	**9–13**	**8–12**
Telial hosts					
Juniperus spp.	H	H	H	H	H
Telia					
Swellings/galls	Fusiform swellings	Long swellings on the branches	Slight fusiform swellings of twigs/ branches	Fusiform cankers/large gall–like swellings/ hemispheric swellings along sides of branches	Irregularly fusiform swellings
Telia shape	Conic/tongue–shaped to a truncate tip	Cylindrical, slightly tapered	Conic	Cushion–like (dry)/swollen irregular tremelloid (moist)	–
Telia size	Up to 10 mm length	–	Up to 8 mm high × 1–2 mm wide	–	Cushion–like
Colour	Chestnut–brown	Orange to cinnamon	Chestnut–brown	Chocolate–brown to pale	Dark–brown
Teliospores					
Number of cells	2 cells	2 cells	2 cells	2 cells	2 cells
Size (µm)	42–56 × 22–32	**45–100 × 12–20**	35–60 × 19–30	40–60 × 20–30	29–58 × 15–25
Colour	Yellow to cinnamon	Hyaline to golden	Hyaline to cinnamon	Yellowish to golden	Yellow–brown
Number of pores per cell	2 pores, near septum	2 pores, near septum	2 pores, near septum	2 pores, near septum	1–2 pores, near septum

H = reported as host.

fungus also infects apple, quince and other rosaceous species, but less severely than on pear. Aecia, 0.3–0.5 mm in diameter, are cupulate and white aeciospores, 12–20 × 14–32 µm, are globose and subangular. The telial stage occurs on *Libocedrus decurrens*, on which it sometimes causes witches' brooms. Telia are reddish brown, scattered, cushionlike and 1–2 mm in diameter. Teliospores, 19–30 × 35–87 µm, are one- to five-celled, brown and liniar-oblong (Laundon, 1977).

G. nelsoni causes **Rocky mountain pear rust** on pear in the Rocky Mountain states. It affects pear leaves and fruits. Besides pear, it occurs on native crab apples, hawthorns and other rosaceous species. The pathogen causes **Nelson's juniper rust** on its telial hosts, *Juniperus scopulorum* and other *Juniperus* spp. Aeciospores are globoid, broadly ellipsoid, 20–32 × 17.5–28 µm, wall 2.0–3.5 µm thick, yellow-brown and densely verrucose. Teliospores are narrowly to broadly ellipsoid, not constricted at septum, 35–55 × 18–28 µm, wall pale to dark yellow-brown, 0.7–3.2 µm thick, 1–2 pores per cell at septum (Parmelee, 1979).

Reporting and documentation

Guidance on reporting and documentation is given in EPPO Standard PM 7/77 (1) Documentation and reporting on a diagnosis.

Acknowledgements

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References

Aldwinckle HS (1990) Rust diseases. *Compendium of Apple and Pear Diseases*, pp. 10–14. American Phytopathological Society, St. Paul (US).

EPPO/CABI (1997) *Gymnosporangium asiaticum*; *G. clavipes*; *G. globosum*; *G. juniperi-virginianae*; *G. yamadae*. *Quarantine Pests for Europe*, 2nd edn, pp. 782–800. CAB International, Wallingford (GB).

Laundon G (1977) *Gymnosporangium asiaticum*. *CMI Descriptions of Pathogenic Fungi and Bacteria No. 541*. CAB International, Wallingford (GB).

Laundon G (1977) *Gymnosporangium clavariiforme*. *CMI Descriptions of Pathogenic Fungi and Bacteria No. 542*. CAB International, Wallingford (GB).

Laundon G (1977) *Gymnosporangium clavipes*. *CMI Descriptions of Pathogenic Fungi and Bacteria No. 543*. CAB International, Wallingford (GB).

Laundon G (1977) *Gymnosporangium confusum*. *CMI Descriptions of Pathogenic Fungi and Bacteria No. 544*. CAB International, Wallingford (GB).

Laundon G (1977) *Gymnosporangium fuscum*. *CMI Descriptions of Pathogenic Fungi and Bacteria No. 545*. CAB International, Wallingford (GB).

Laundon G (1977) *Gymnosporangium globosum*. *CMI Descriptions of Pathogenic Fungi and Bacteria No. 546*. CAB International, Wallingford (GB).

Laundon G (1977) *Gymnosporangium juniperi-virginianae*. *CMI Descriptions of Pathogenic Fungi and Bacteria No. 547*. CAB International, Wallingford (GB).

Laundon G (1977) *Gymnosporangium libocedri*. *CMI Descriptions of Pathogenic Fungi and Bacteria No. 548*. CAB International, Wallingford (GB).

Laundon G (1977) *Gymnosporangium tremelloides*. *CMI Descriptions of Pathogenic Fungi and Bacteria No. 549*. CAB International, Wallingford (GB).

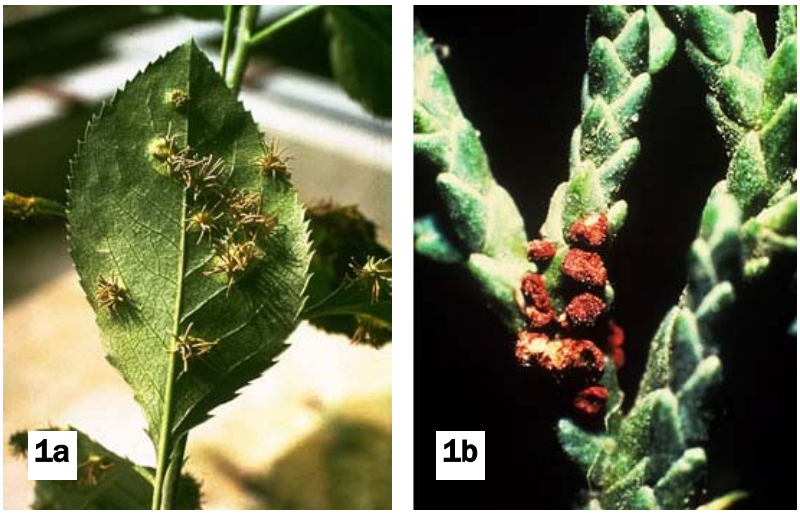
Laundon G (1977) *Gymnosporangium yamadae*. *CMI Descriptions of Pathogenic Fungi and Bacteria No. 550*. CAB International, Wallingford (GB).

Parmelee JA (1978) *Gymnosporangium Cornutum, Fungi Canadenses No. 117*. National Mycological Herbarium, Biosystematics Research Institute, Ontario (CA).

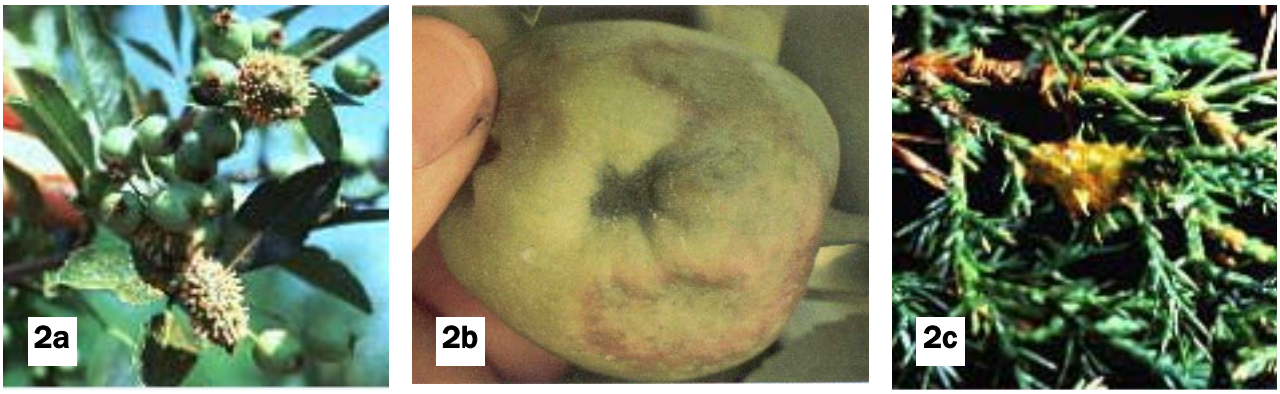
Parmelee JA (1979) *Gymnosporangium Nelsonii*. *Fungi Canadenses No. 138*. National Mycological Herbarium, Biosystematics Research Institute, Ontario (CA).

Sinclair WA, Lyon HH & Johnson WT (1987) *Gymnosporangium rusts*. *Diseases of Trees and Shrubs*, pp. 240–249. Comstock Publishing Associates, Ithaca and London (US and GB).

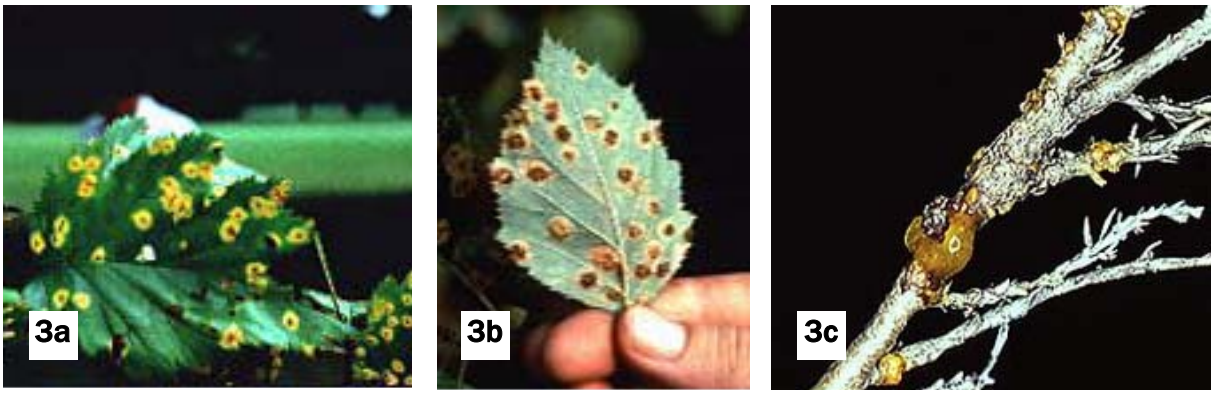
Appendix 1: Pictures of symptoms caused by *Gymnosporangium* spp.



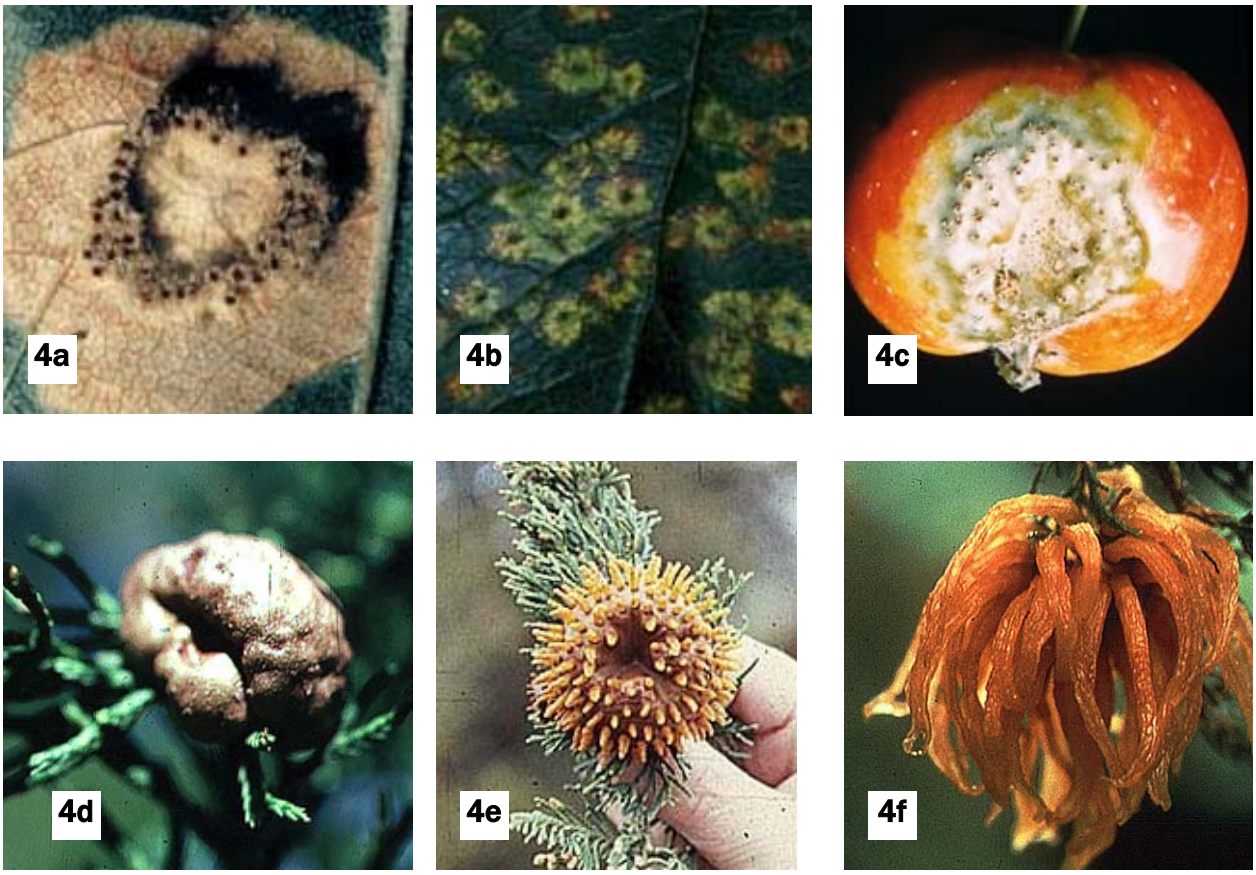
Web Fig. 1: Symptoms caused by ***G. asiaticum*** on under surface pear leaf (a) and on *J. chinensis* (b).



Web Fig. 2 Symptoms caused by ***G. clavipes*** on hawthorn fruit (a), on a Delicious apple (b) on Juniper (c).



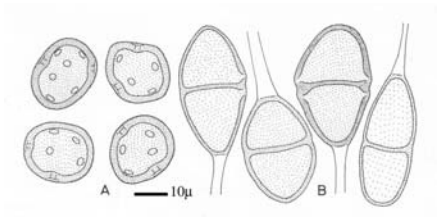
Web Fig. 3 Symptoms caused by ***G. globosum*** on upper leaf surface of hawthorn (a), on lower surface of hawthorn leaf (b) and on juniper.



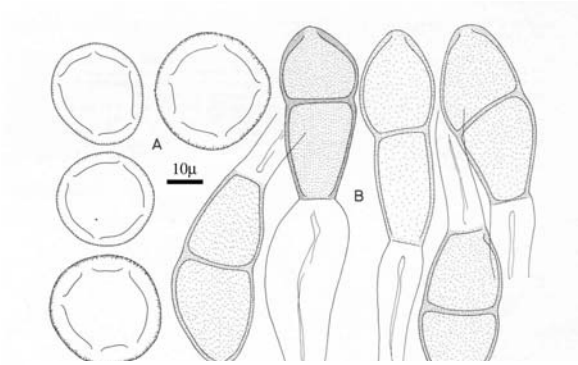
Web Fig. 4 Symptoms caused by ***G. juniperi*-virginianae** on underside of apple leaf showing aecia (a), on upper surface of apple leaf (b), on apple fruit showing aecia (c), on juniper showing gall formation (d), on juniper with emerging teliohornes on galls (e), and on juniper showing gall with mature teliohornes (f).

Web Fig. 5 Symptoms caused by ***G. yamadae*** on lower apple leaf showing aecia (a).

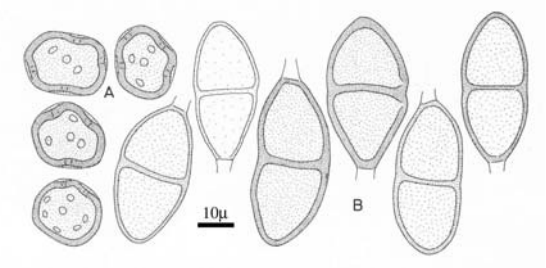
Appendix 2: Illustrations of spores of *Gymnosporangium* spp. (after Laundon, 1977)



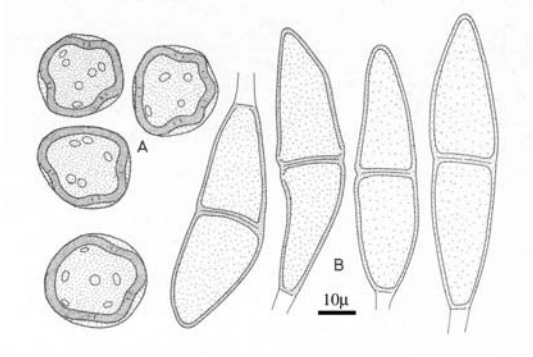
Web Fig. 6 Aeciospores (A) and teliospores (B) of *Gymnosporangium asiaticum.*



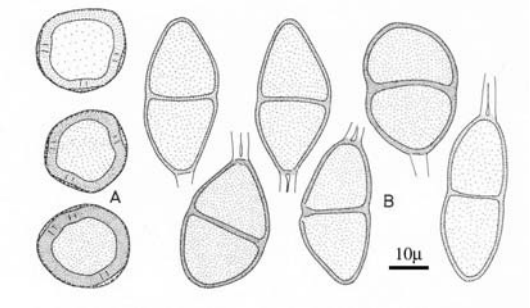
Web Fig. 7 Aeciospores (A) and teliospores (B) of *Gymnosporangium clavipes.*



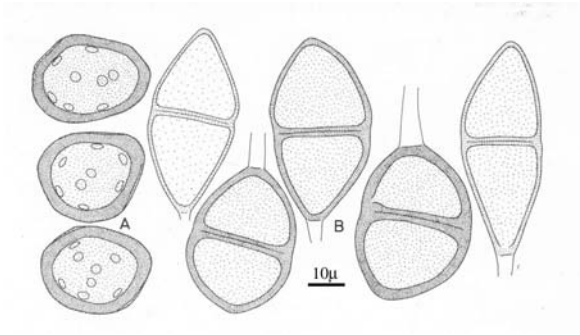
Web Fig. 8 Aeciospores (A) and teliospores (B) of *Gymnosporangium globosum.*



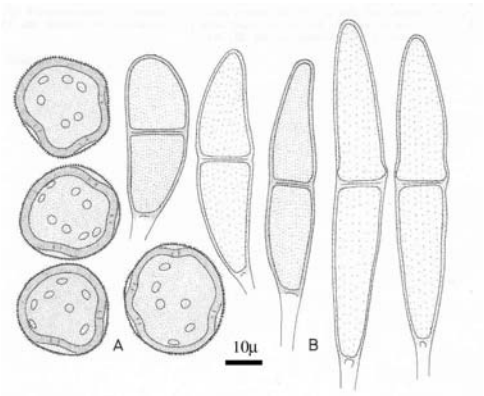
Web Fig. 9 Aeciospores (A) and teliospores (B) of *Gymnosporangium juniperi-virginianae.*



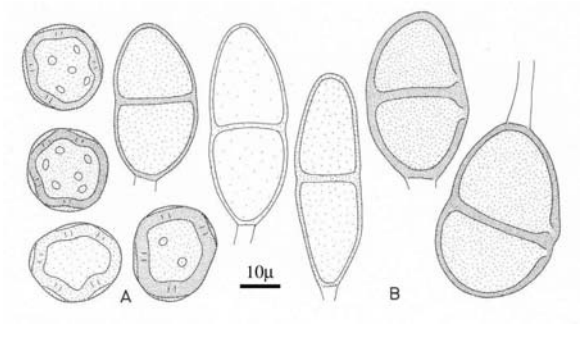
Web Fig. 10 Aeciospores (A) and teliospores (B) of *Gymnosporangium yamadae.*



Web Fig. 11 Aeciospores (A) and teliospores (B) of *Gymnosporangium fuscum.*



Web Fig. 12 Aeciospores (A) and teliospores (B) of *Gymnosporangium clavariiforme.*



Web Fig. 13 Aeciospores (A) and teliospores (B) of *Gymnosporangium confusum.*