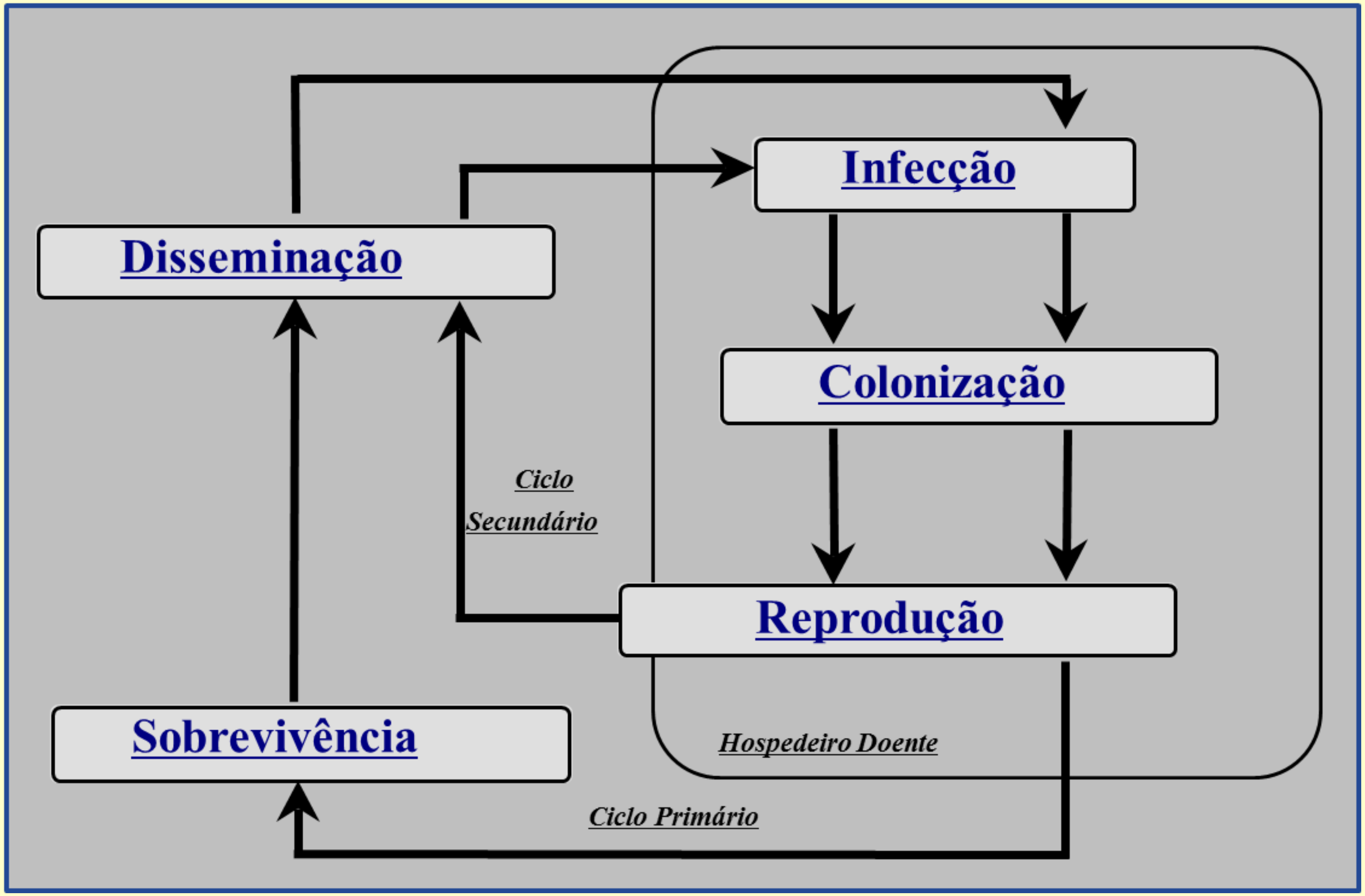
Ciclo das relações patógeno-hospedeiro



COLONIZAÇÃO

- **Como o patógeno coloniza o hospedeiro?**
  relações tróficas

- Como o patógeno conquista diferentes partes do hospedeiro?
  sistemicidade / infecção localizada

- Quanto tempo demora a colonização?
  conceito de latência

COLONIZAÇÃO

Como o patógeno coloniza o hospedeiro?

Parasitismo
Relações nutricionais

Biotrófico → Cutinases, celulases, etc
Pequena quantidade

Hemibiotrófico

Necrotrófico → Pectinases, celulases, etc.
Grande quantidade

Biotróficos

Oidios - *Oidium, Ovulariopsis, Oidiopsis*

Ferrugens - *Puccinia*, *Uromyces*, *Melampsora, Tranzschelia*, *Hemileia ...*

Míldios - *Plasmopara*, *Peronospora*

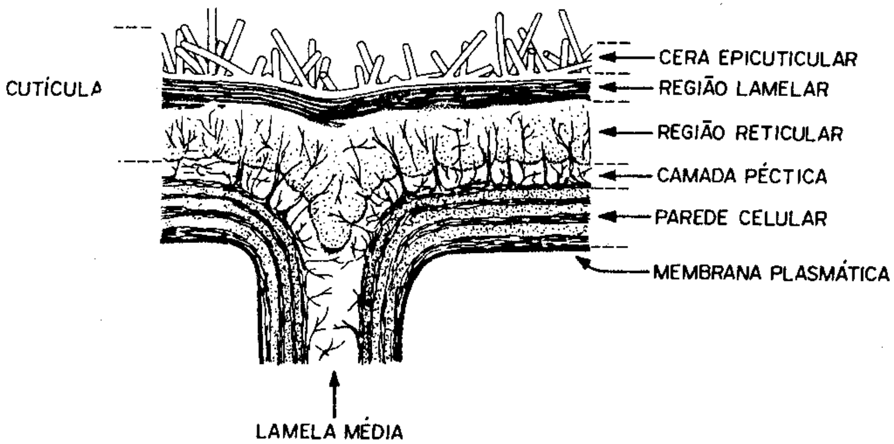
Carvões - *Ustilago, Tilletia*

Fitoplasmas e Espiroplasmas

Vírus e Viróides

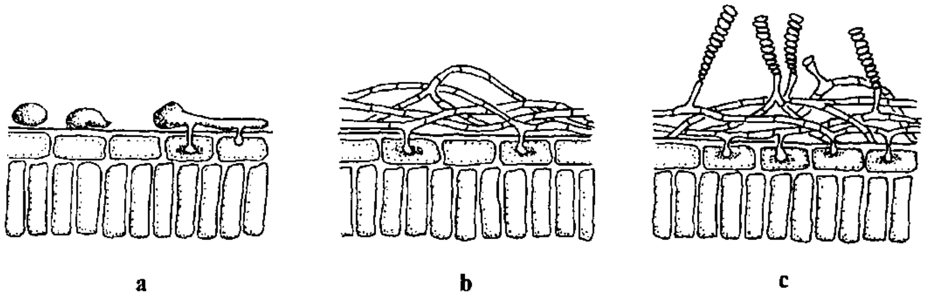
Patógenos biotróficos

Superfície vegetal

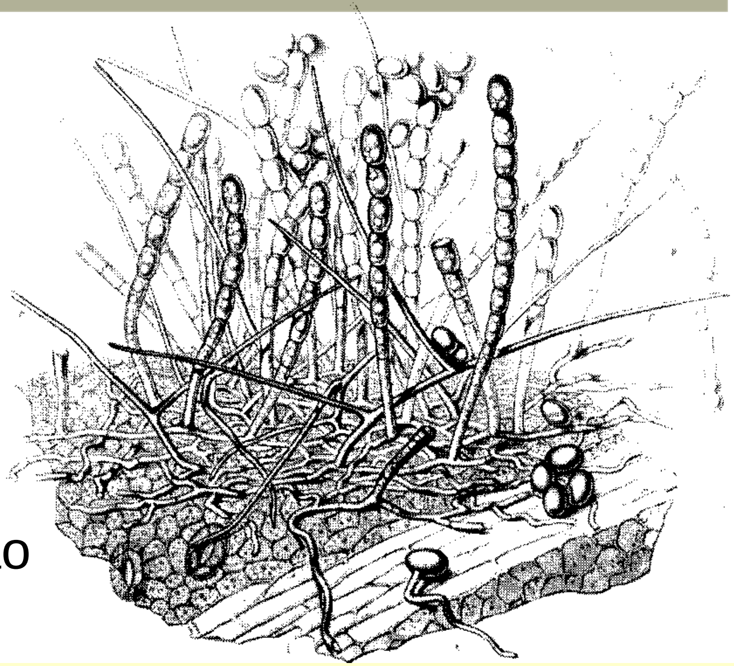


Oídios

- Penetração direta e apressório
- Haustório em células epidérmicas
- Hifas sobre a cutícula



a = infecção, b = colonização, c = reprodução



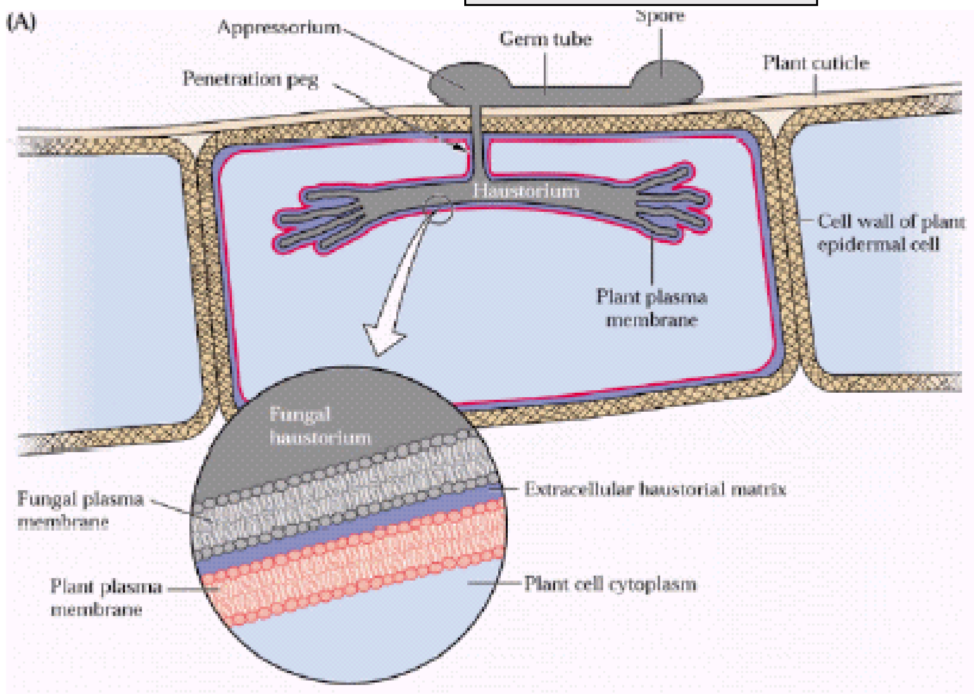
Patógenos biotróficos

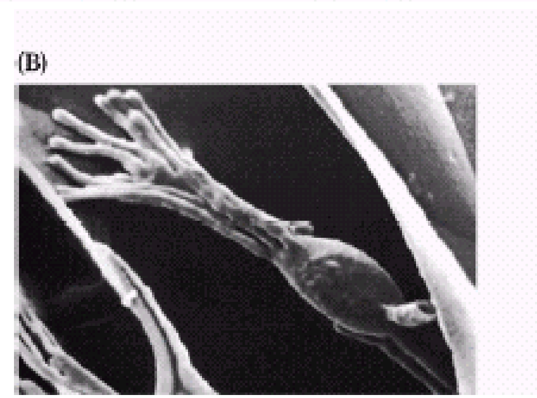
Oídios

Fungal haustorium -

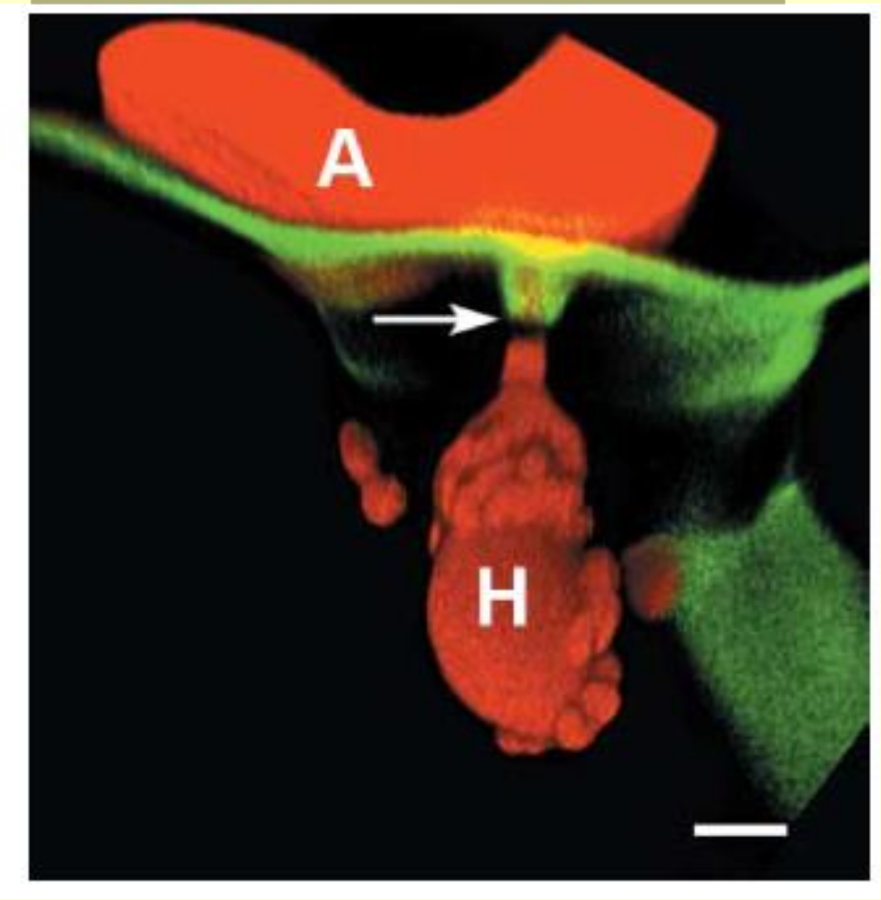
-facilitates the transfer of nutrients from a living plant cell. The extracellular matrix is made of both plant and fungal membranes.

(B) scanning EM of a haustorium of the biotropic barley mildew fungus *Erysiphe graminis* inside a barley epidermal cell.





Patógenos biotróficos



Oídios

Parede e membrana plasmática do haustório diferentes do restante: composição (carbohidratos e gicoproteínas específicas) e função (transporte de nutrientes)

Membrana da planta extra-haustório diferente do restante: corrugada, mais fina

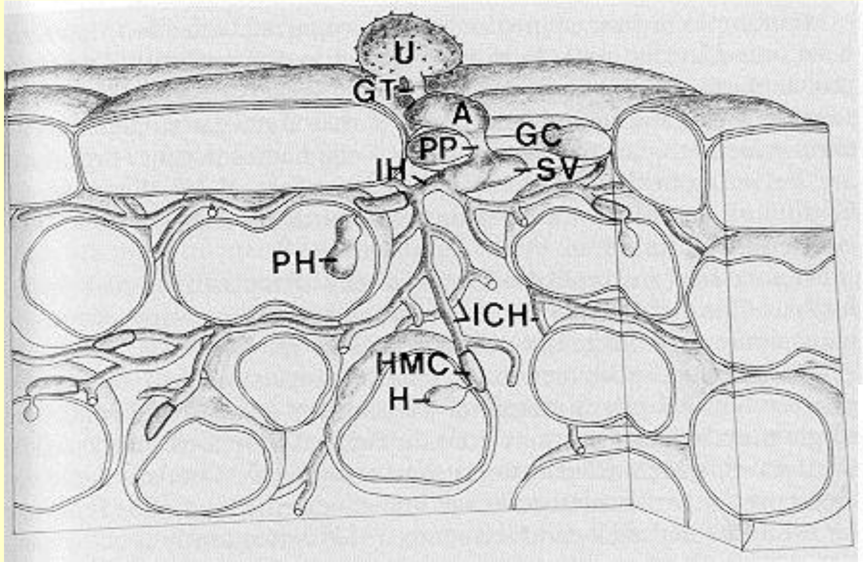
Fig. 4 A live-cell confocal microscope image illustrating differentiation of the extrahaustorial membrane around a haustorium (H) of *Erysiphe cichoracearum* in an epidermal cell of *Arabidopsis thaliana*. A green fluorescent protein (GFP)-tagged plasma membrane marker, shown in green, is present in the plasma membrane but is excluded around the haustorial body, with an abrupt transition in membrane labelling at the haustorial neck (arrow). Fungal structures are stained red with propidium iodide. A=appressorium.

New Phytologist (2006) **171** : 699–718

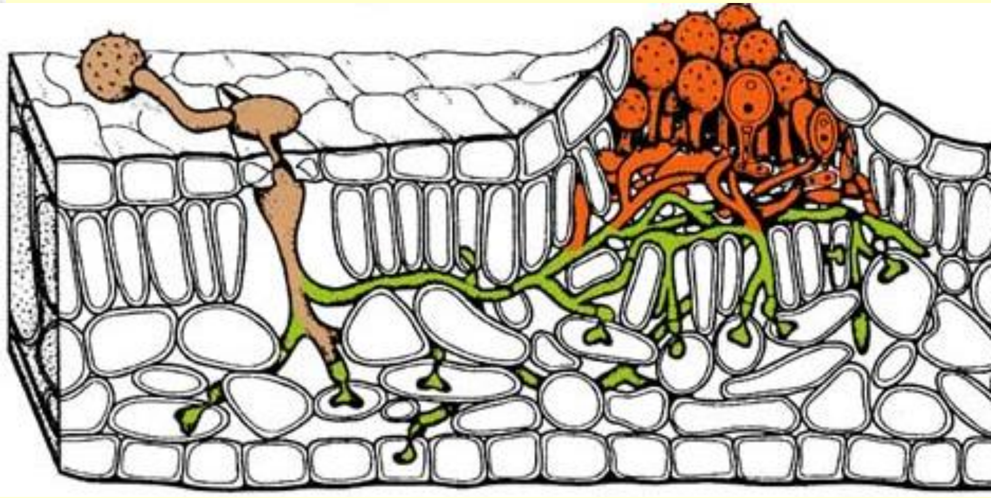
Patógenos biotróficos

Ferrugens

- Penetração por estômatos / direta
- Haustório em células do mesófilo
- Hifas intercelulares

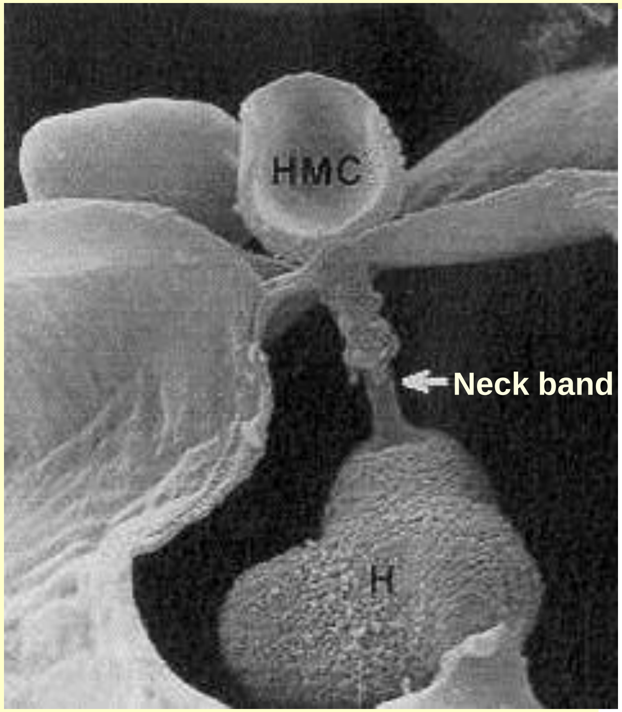


U = uredósporo, GT = tubo germinativo, A = apressório, PP = peg de penetração, GC = célula guarda do estômato, SV = vesícula subestomática, IH = hifa de infecção, ICH = hifa intercelular, HMC = célula mãe do haustório, H = haustório, PH = haustório primário



Patógenos biotróficos

Ferrugens



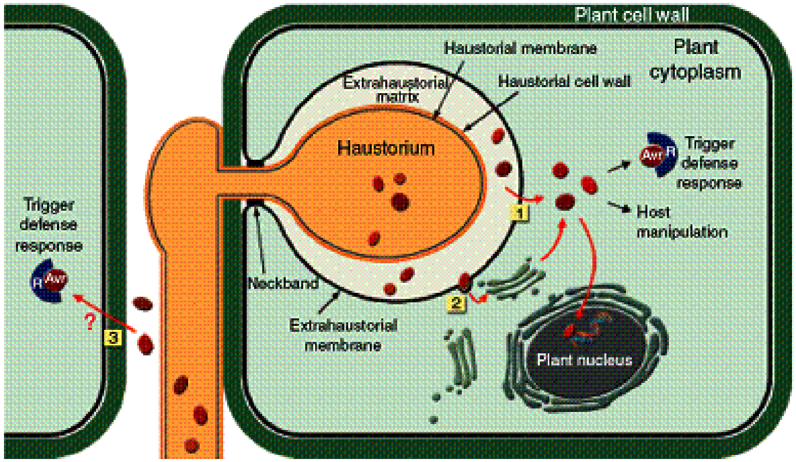


Fig. 1. The host–haustorium interface. Schematic diagram of a rust haustorium within a host cell showing the extrahaustorial membrane and the extrahaustorial matrix, which is thought to be a discrete compartment due to the presence of the neckband, note that this feature is absent from oomycete haustoria. Effector proteins are secreted from the haustoria into the extrahaustorial matrix. A subset of proteins are further transported into the host cell, either directly crossing the extrahaustorial membrane (1) or through vesicles into the host endomembrane system (2). Once inside the host cytoplasm, effectors may alter host metabolism and defence pathways. Those effectors that are recognized by resistance gene products (R) are known as avirulence proteins (Avr) and trigger a defense response. Other effectors may be further targeted to host organelles such as the nucleus to alter host transcription. Effectors secreted from the hyphae into the apoplast may also enter plant cells via an unknown mechanism (3), and when recognized by a resistance protein, trigger a defense response.

(Catanzariti et al. 2007)

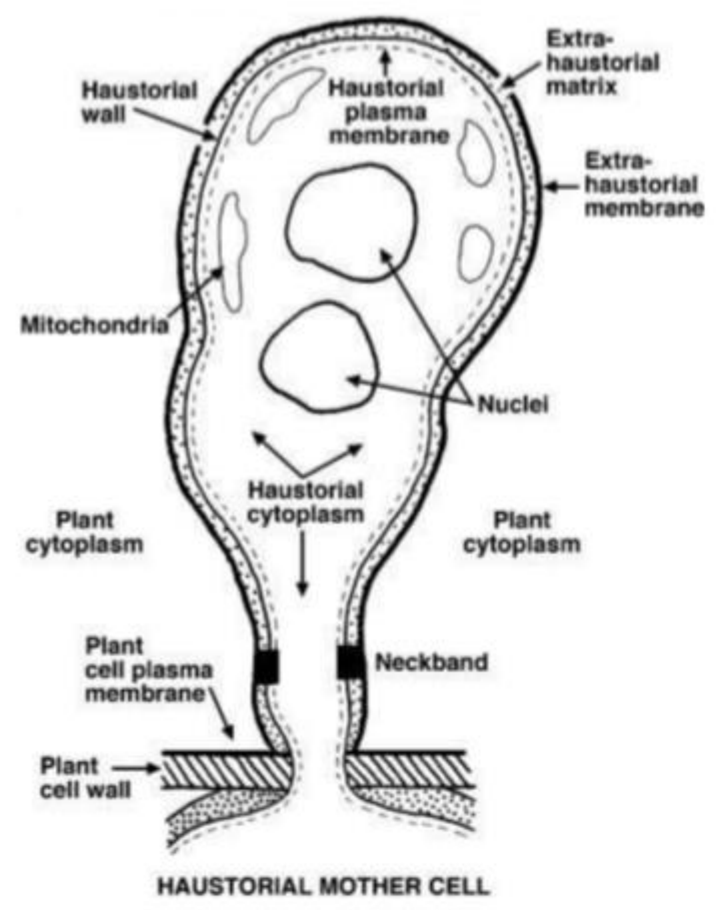
HMC = CÉLULA MÃE DO HAUSTÓRIO
H = HAUSTÓRIO DE *Hemileia vastatrix*

Neck band - contenção da matrix extrahaustório

Haustoria formation induces substantial re-organization of the host-cell cytoskeleton, nuclear DNA and endomembrane system

Patógenos biotróficos

Ferrugens



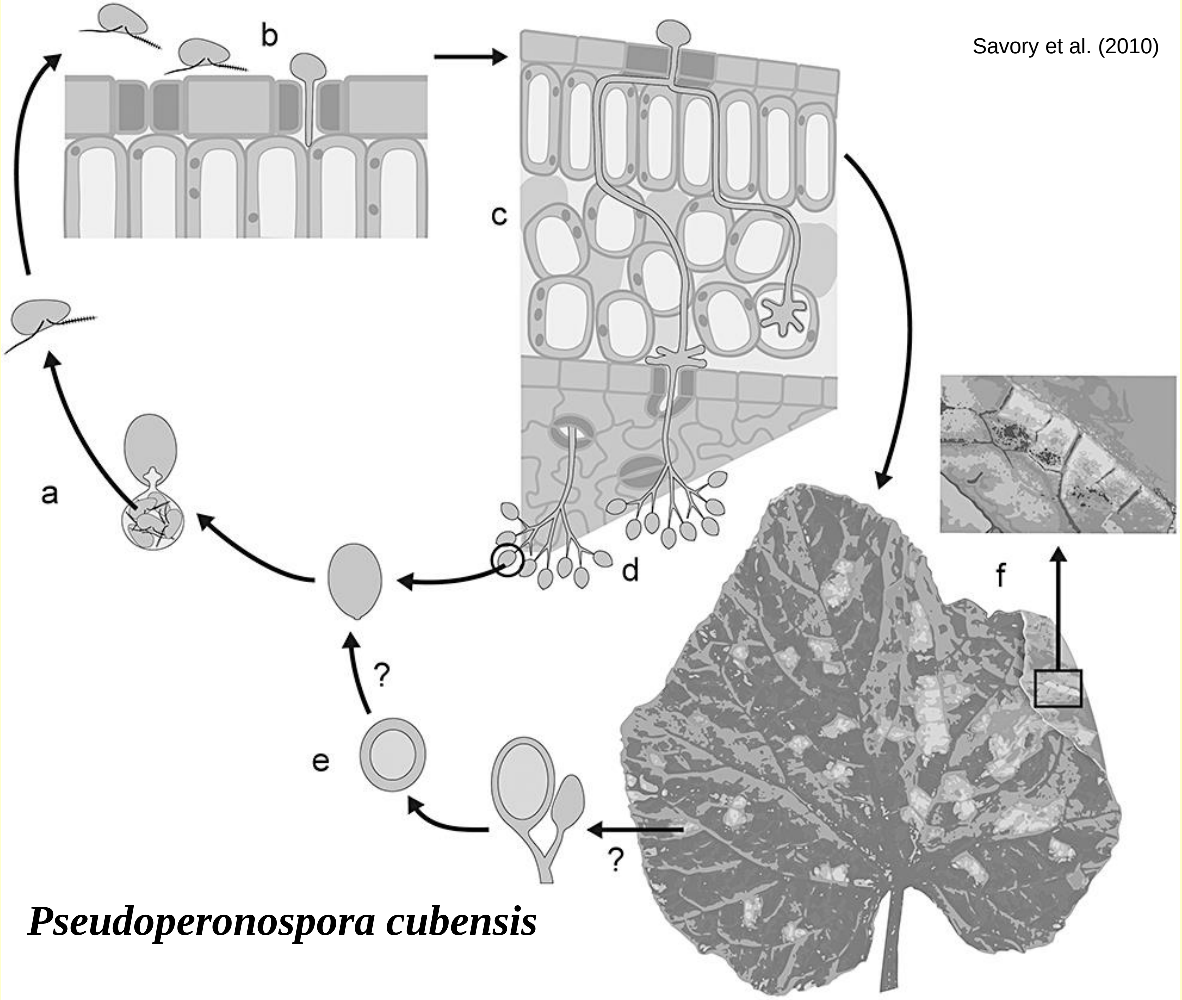
(Leonard & Szabo, 2005)

Fig. 4 Diagram of a typical haustorium of *P. graminis*. The interface between the plant and fungal cytoplasm comprises haustorial plasma membrane, haustorial wall, extrahaustorial matrix (a gel-like layer enriched in carbohydrates) and the extrahaustorial membrane (derived from the invaginated plant plasma membrane). A neckband seals the extrahaustorial matrix from the plant cell wall region so that the matrix is an isolated, apoplastic-like compartment. The haustorium contains cytoplasm, two nuclei and mitochondria, as well as other cellular components, and is directly connected to the haustorial mother cell through which nutrients are transported to the developing fungal hyphae.

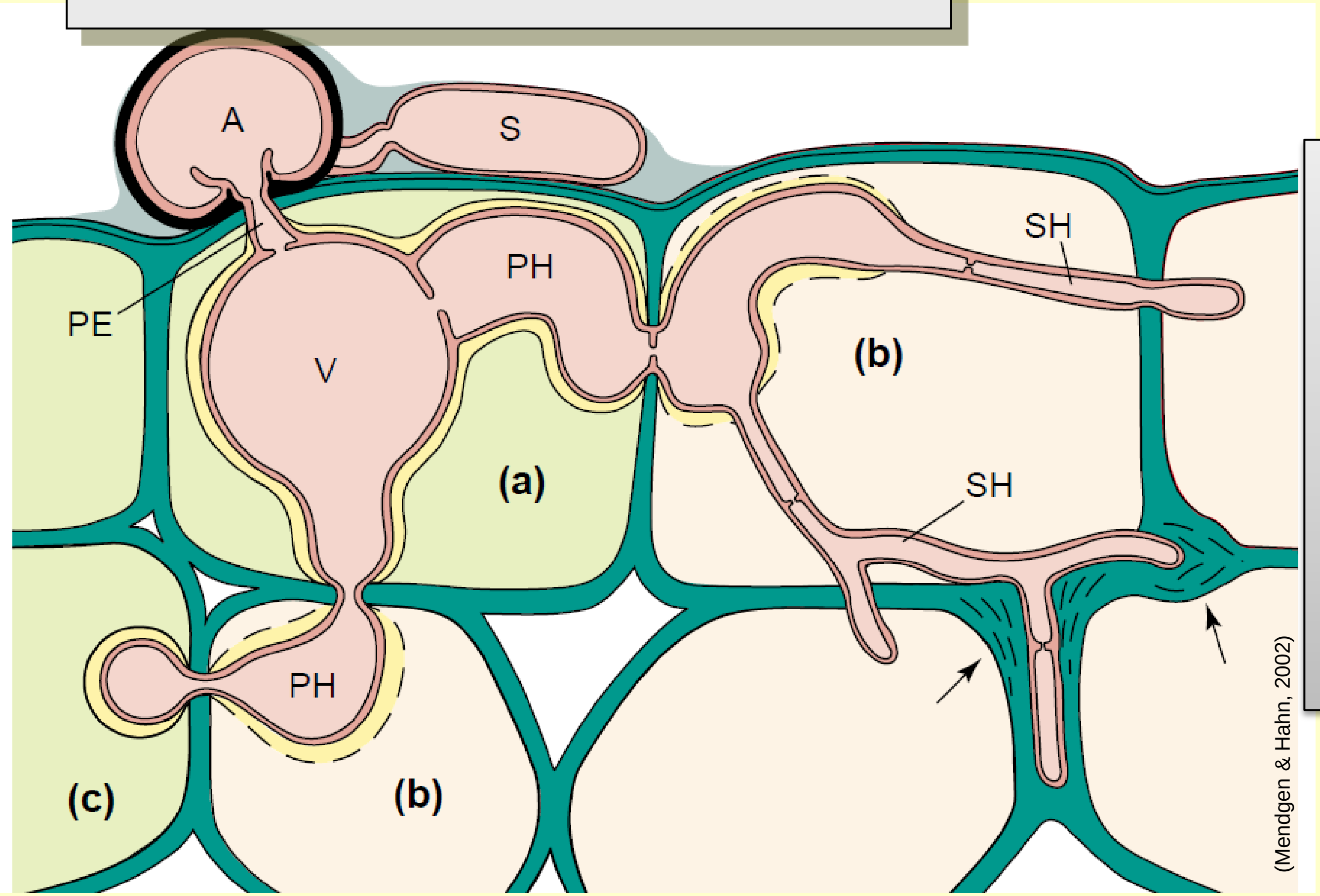
Patógenos biotróficos

Míldios

Colucci et al. (apsnet.org)



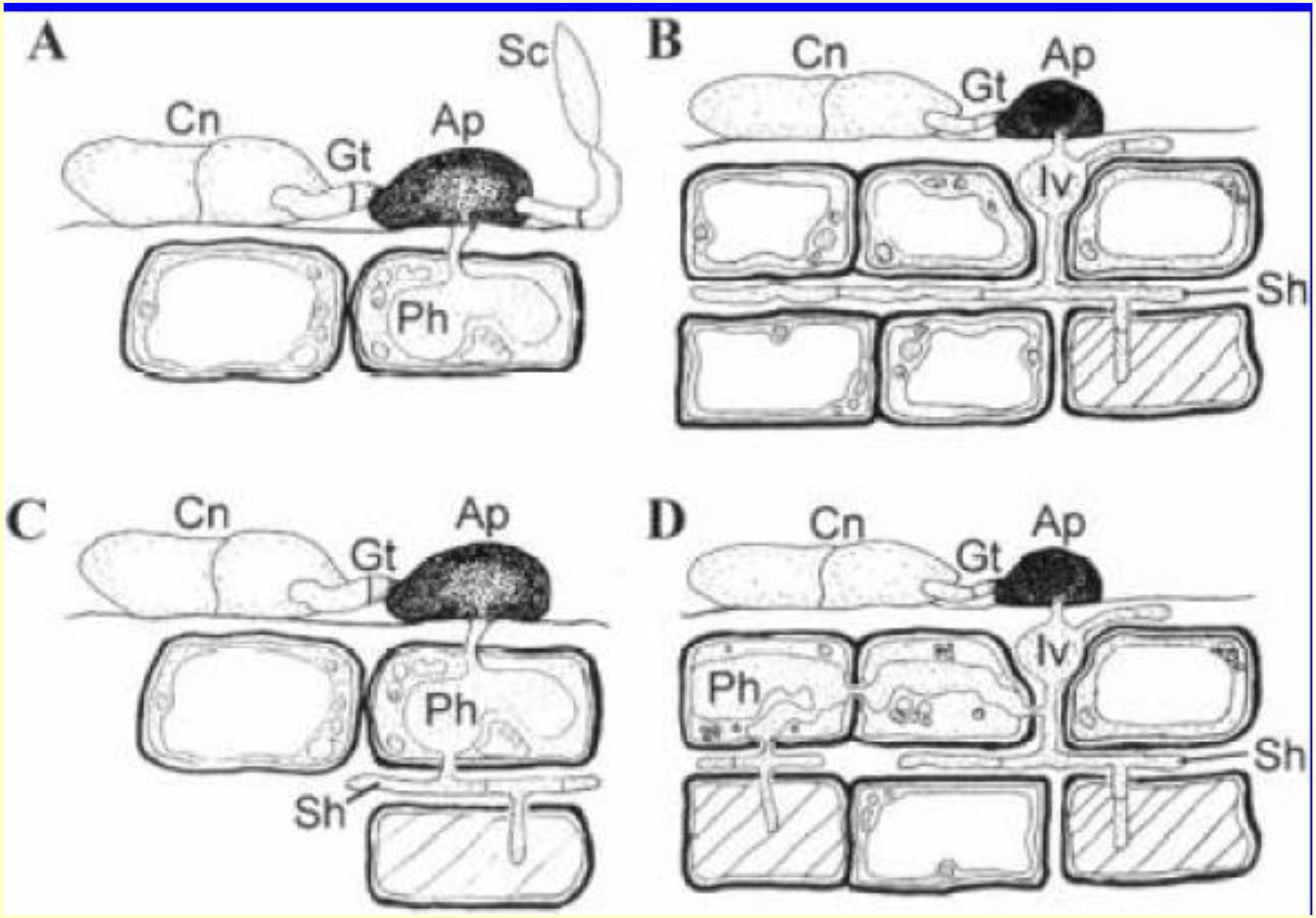
Patógenos hemibiotróficos



Phytophthora infestans - Batata
Moniliophthora perniciosa - Cacau
Colletotrichum destructivum – *Vigna*
C. graminicola – Milho
C. lindemuthianum – Feijão
C. truncatum – Ervilha

Fig. 1. Hemibiotrophic infection by *Colletotrichum lindemuthianum*. A spore (S) attached to the hostsurface germinates to form a short germ tube, which differentiates into a domed, melanized appressorium (A). The penetration hypha (PE) develops on the appressorium baseand swells within the epidermal cell to form a vesicle (V) and broad primary hyphae (PH), which are surrounded by the invaginated plant plasma membrane. The host protoplast remains alive during the biotrophic stage (a) and an interfacial matrix separates the protoplasts of fungus and host (yellow). One or two days after penetration, plant plasma membrane disintegration starts, leading to host cell death (b). As new host cells are colonized by primary hyphae, the sequence of a transient biotrophic phase followed by cell killing is repeated (c). This relationship ends as soon as narrow secondary hyphae (SH) develop, which are not surrounded by the host membrane and lack an interfacial matrix. Host walls break down because of the secretion of large amounts of cell-wall-degrading enzymes by the secondary hyphae (arrows)

Colletotrichum acutatum



A – biotrófico, B – necrotrófico, C e D - hemibiotrófico

Peres et al. Plant Disease 89(8): 784-96. 2005

Patógenos hemibiotróficos

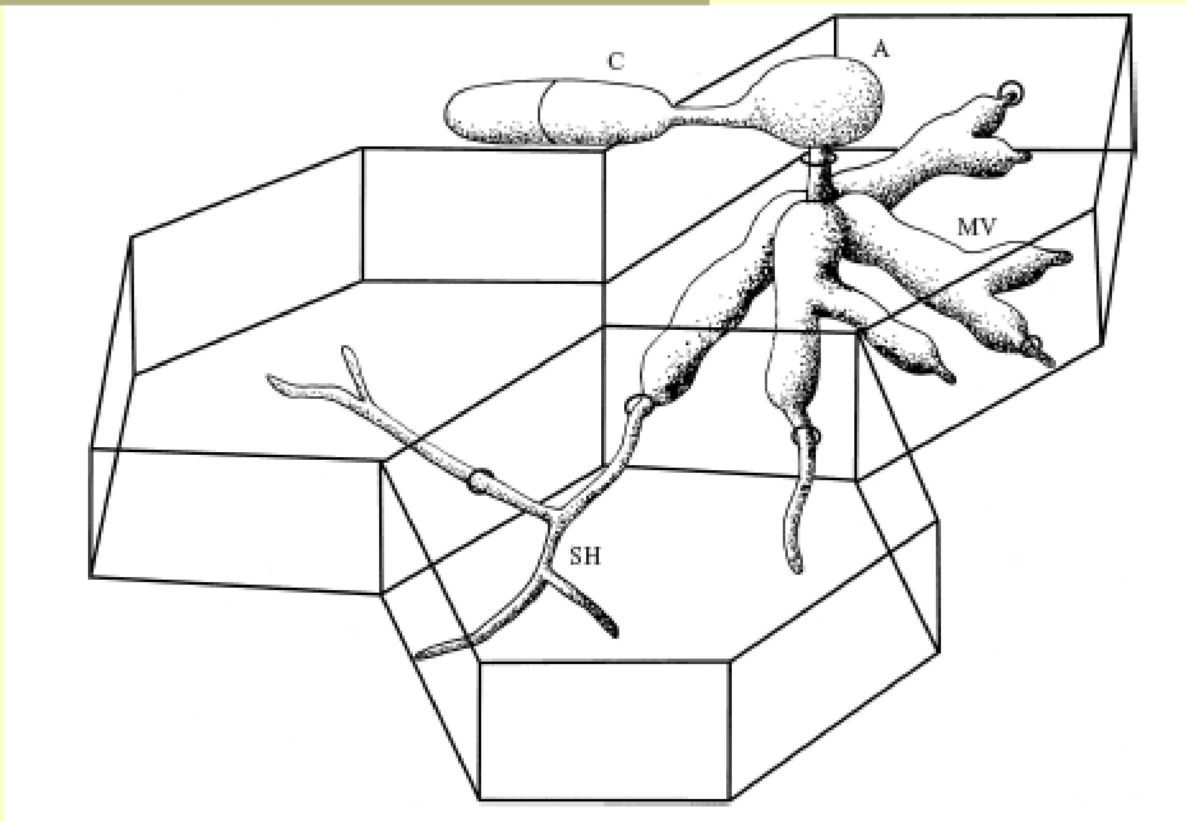


Fig. 14. Diagrammatic view of infected tobacco epidermal cells showing the septate conidium (C), appressorium (A), penetration peg below the appressorium, multi-lobed vesicles (MV) and thin secondary hyphae (SH) growing from the vesicles.

Mycol. *Res*. **105** (11) : 1340–1347. 2001

Patógenos hemibiotróficos

Phytophthora infestans

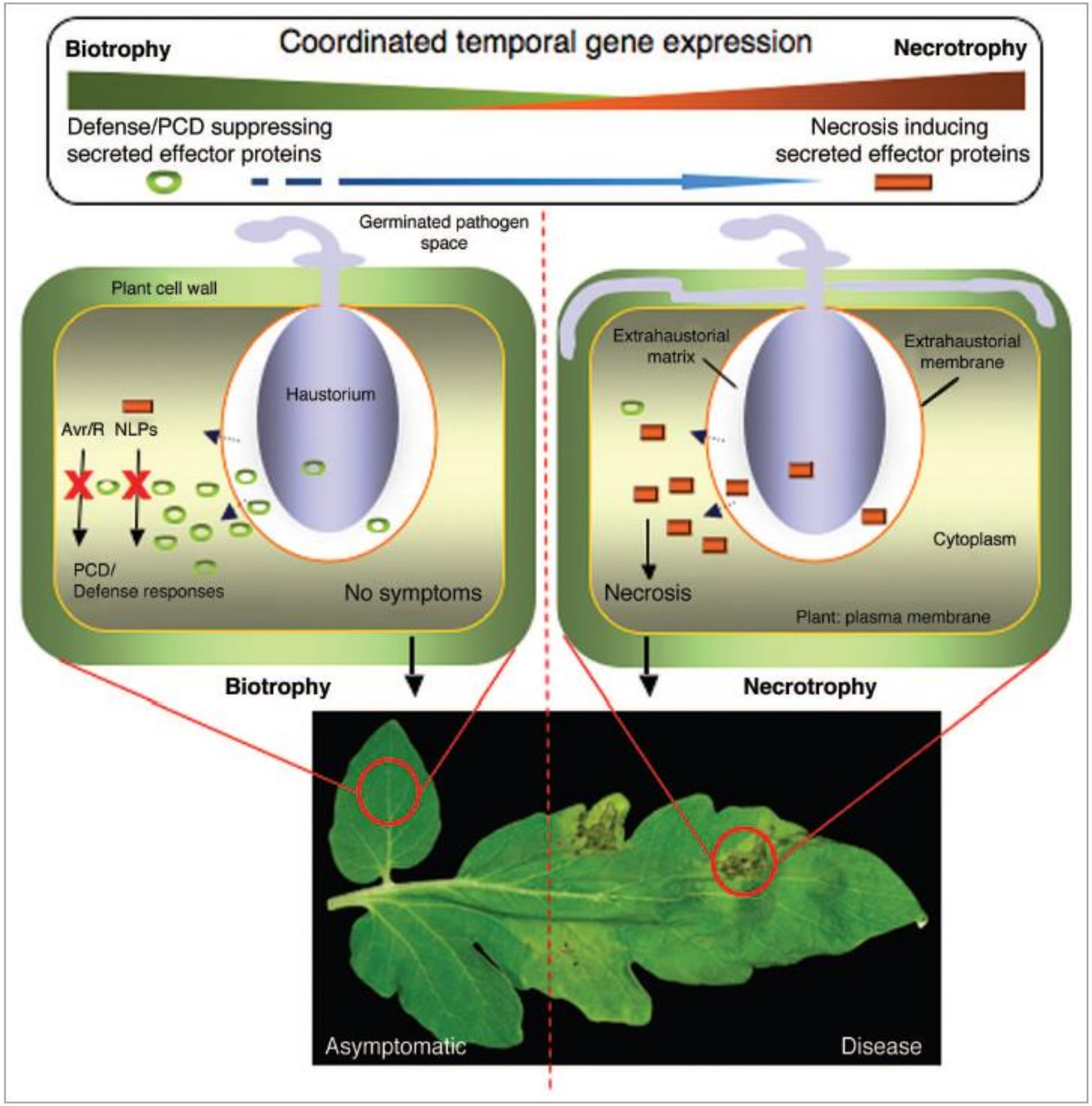


Figure 1. Hypothetic model of coordinated effector protein secretion by *Phytophthora infestans* during the sequential stages of biotrophy and necrotrophy, providing a means to regulate hemibiotrophy. On the left hand side, secreted effector proteins that are expressed in the initial phases of infection, such as SNE1, act to block programmed cell death (PCD) and plant defense responses that would normally be induced by *Avr/R* gene interactions and secreted protein such as NLPs, resulting in no symptoms of infection. In contrast, on the right hand side, later in infection when the pathogen has extensively proliferated through the host tissue, the secretion of proteins such as NLPs induces rapid cell death and tissue necrosis. A photograph illustrating each phenomenon in circled areas of a *P. infestans* infected tomato leaf is shown at the bottom.

Lee & Rose (2010)

Patógenos hemibiotróficos

Moniliophthora perniciosa – Vassoura de bruxa do cacaueiro

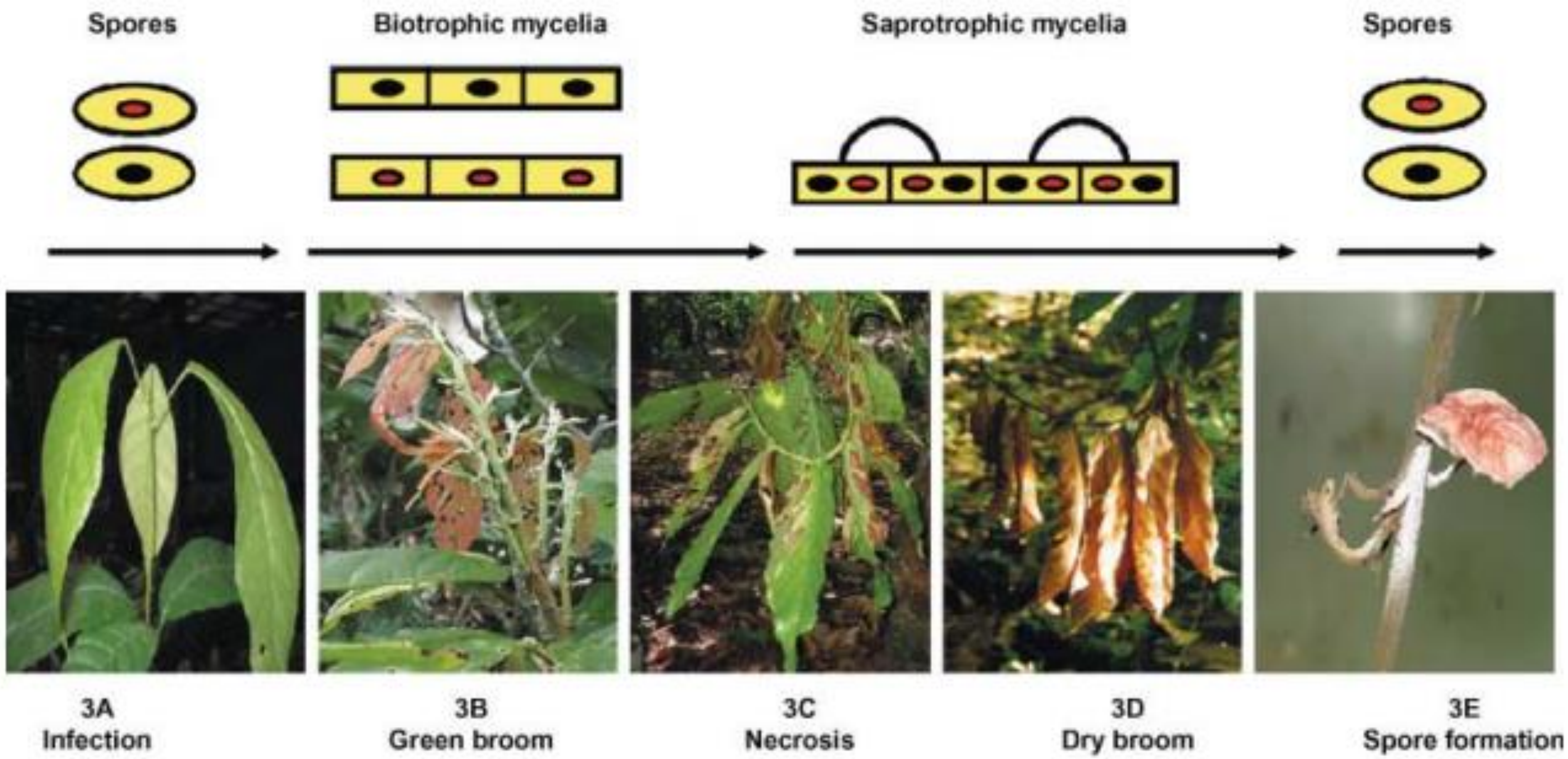
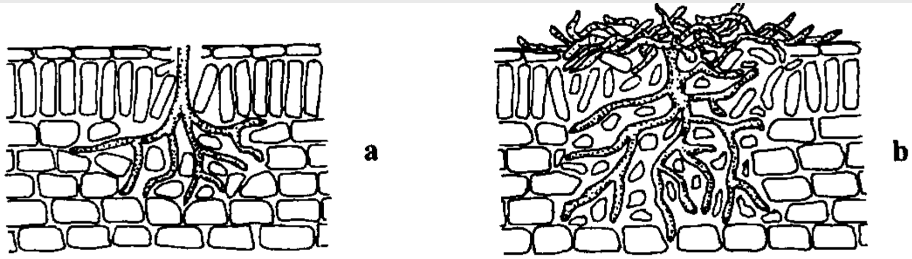


Fig. 3 Disease progression (left to right). The images of the fungal stage above represent the progression of the fungus from the biotrophic phase to the saprotrophic phase and the typical mycelial structures and nuclei number at each symptomatic stage shown below. (A) Infection by penetration through stomatal opening. (B) Growth of the green broom. (C) Necrosis of infected tissues. (D) Dry broom. (E) Basidiocarp and spore formation.

Patógenos necrotróficos

Rhizopus
Penicillium
Botrytis
Sclerotinia
Bipolaris
Alternaria
Septoria…

Fungos



Bactérias

Erwinia
Xanthomonas
Psudomonas

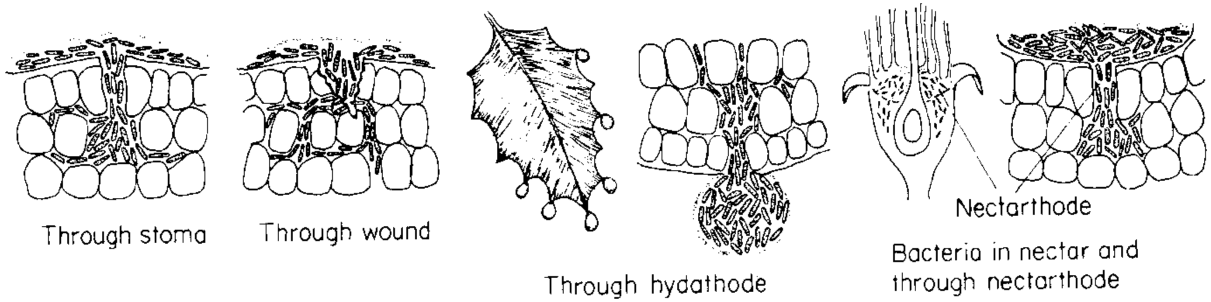
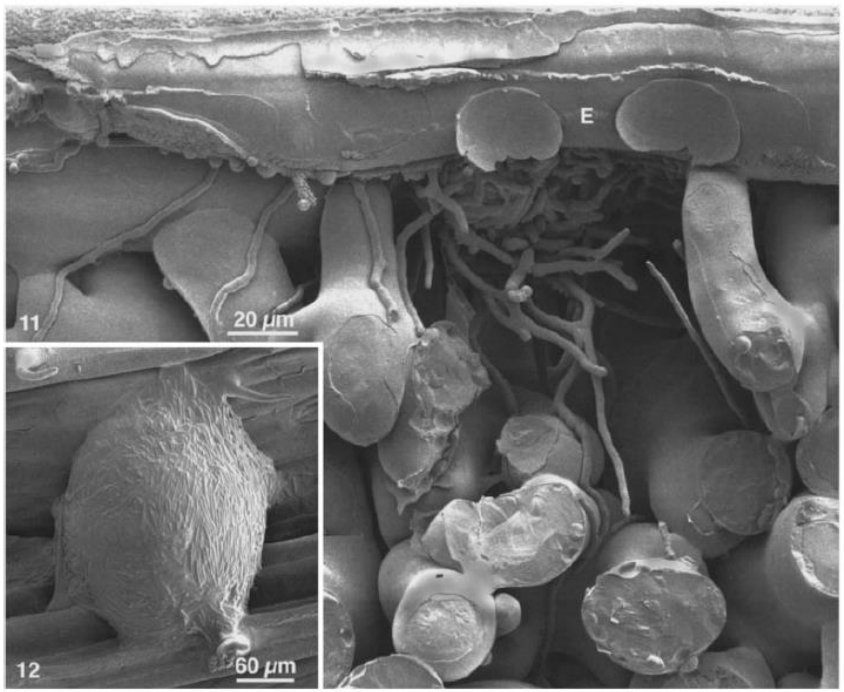


FIGURE 2-5 Methods of penetration and invasion by bacteria.

Patógenos necrotróficos



Figs 11–12. Fig. 11. *Mycosphaerella graminicola* colonized wheat leaf, cryo-fractured at 10 d after inoculation. An incipient pycnidium can be seen as a cluster of intercellular infection hyphae within the substomatal chamber. Note the intercellular spread of hyphae away from the initial site of penetration, into the surrounding mesophyll. Epidermal cell layer, (E). Cryo-SEM image. **Fig. 12.** A *M. graminicola* cirrus – conidium bound together by a mucilaginous material and extruded through a stoma from a mature pycnidium – visible on a leaf surface by cryo-SEM.

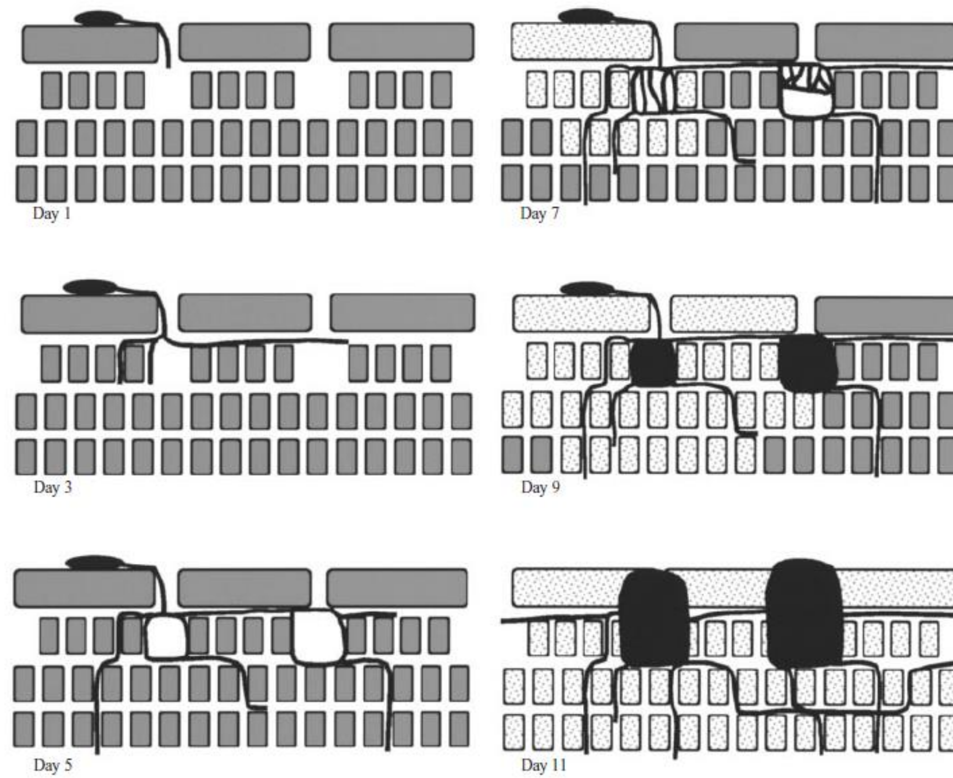


Fig. 13. Summary of wheat leaf blotch disease progress under laboratory conditions. Each panel represents a microscopic, cross sectional view through a portion of wheat leaf depicting cells of the adaxial epidermis and adjacent mesophyll, stomatal openings and substomatal chambers. **Day 1** *Mycosphaerella graminicola* conidia germinate, form a germ tube, and enter a substomatal chamber by penetration through a stoma. **Day 3** Infection hyphae begin colonization of the substomatal chamber by circumscribing its perimeter, and also spread laterally by intercellular invasion of adjacent tissue. **Day 5** Intercellular growth of infection hyphae, both laterally and deeper into tissues of the leaf lamella, can lead to colonization of adjacent substomatal chambers – the result of penetration at a single site. **Day 7** Perpendicular branching leads to a basket weave of infection hyphae around the entire periphery of substomatal chambers. The onset of macroscopic symptoms, depicted by stippling, follows autofluorescence and includes chlorosis and necrosis of host cells. **Day 9** The 'basket' of infection hyphae lining substomatal chambers begins to fill with dense fungal tissue of the pycnidium initials. Macroscopic symptoms continue to develop as autofluorescence and chlorosis of host cells increase. **Day 11** Surrounded by necrotic host cells and now fully mature, pycnidia are visible with the unaided eye, and can exude a cirrus when placed in a moist environment. Infection hyphae continue to spread throughout the leaf lamella.

(Duncan & Howard, 2000)

Colonização bacteriana

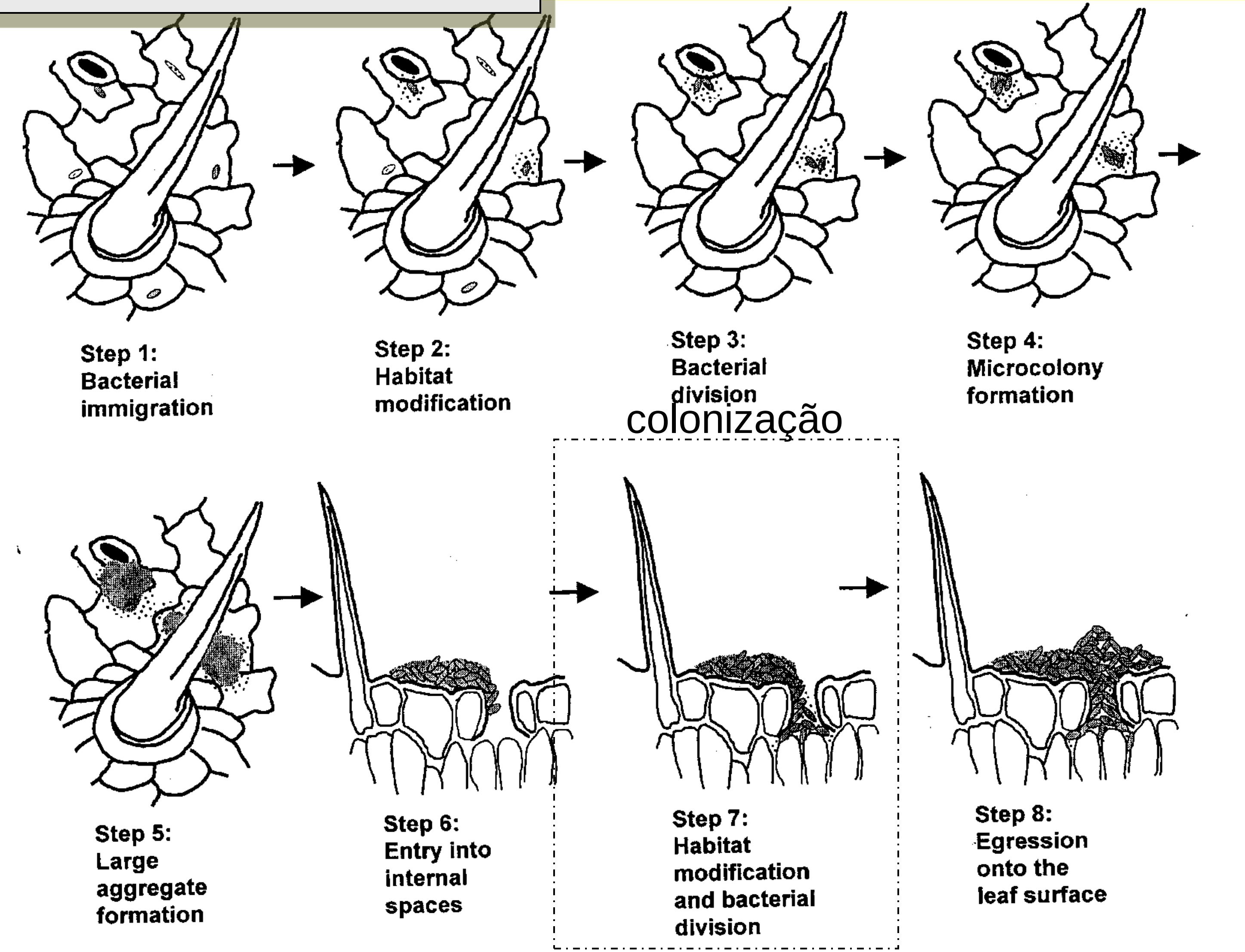
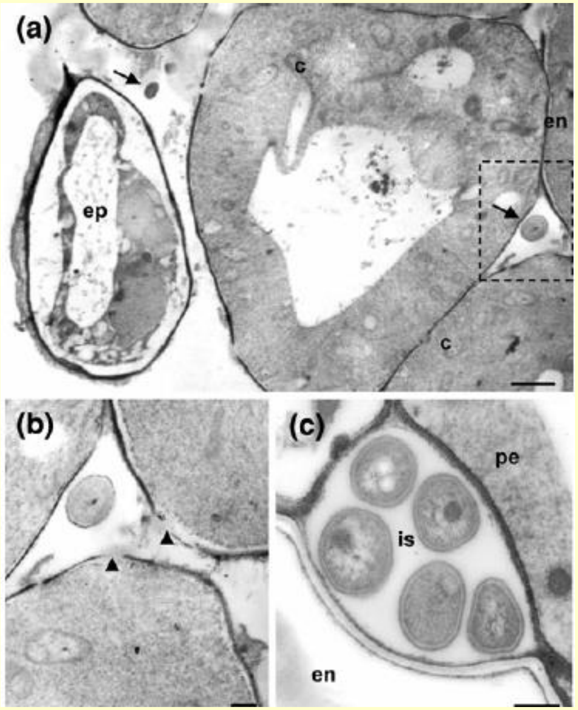


Fig. 1. Model of leaf colonization by phyllobacteria.

Beattie & Lindow. Phytopathology **89: 353-359, 1999**

Colonização bacteriana

Ralstonia solanacearum in intercellular spaces throughout the cortex. TEM observations of transverse sections of Arabidopsis roots at 6 dpi. (a) *R. solanacearum* are present in intercellular spaces between epidermal and cortical cells, and cortical and endodermal cells (arrows). b Close-up of the boxed area in a. Localized cell wall degradation (arrowheads) of cortical and endodermal cells adjacent to the intercellular space is observed. c Bacterial proliferation in an intercellular space between an endodermal and pericycle cell. c cortical cell, en endodermal cell, ep epidermal cell, pe pericycle, is intercellular space. Magnification bars: 1 lm (a), 500 nm (b, c)



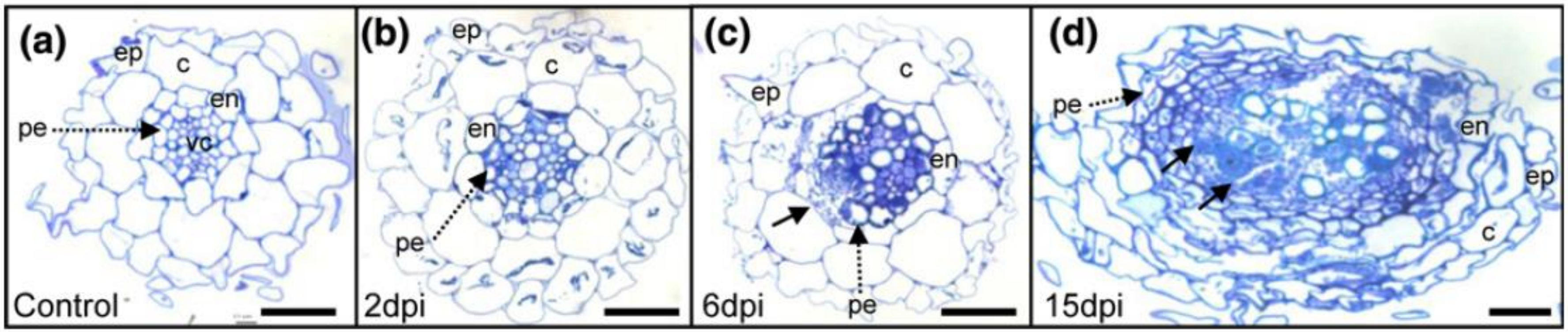
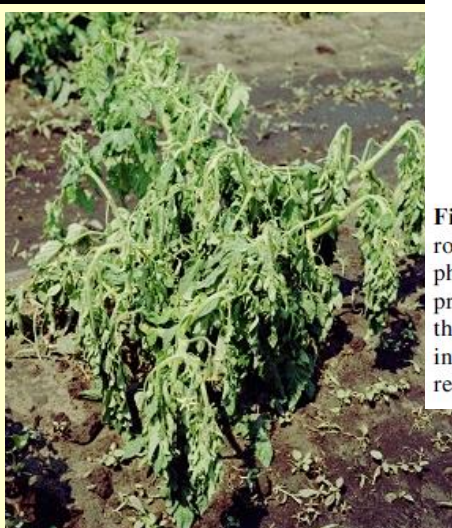


Fig. 2 Overview of *Ralstonia solanacearum* colonization of the *Arabidopsis* root. Transverse root sections were stained with toluidine blue. **a** Roots prior to inoculation. Inoculated roots at 2 dpi (**b**), 6 dpi (**c**), and 15 dpi (**d**). *Arrows* indicate the bacterial pocket and xylem vessels filled with bacteria (**c** and **d**, respectively). *ep* epidermis, *c* cortical cell, *vc* vascular cylinder, *en* endoderm, *pe* pericycle. Magnification *bar* 50 µm

Digonnet et al. (2012)

Colonização bacteriana



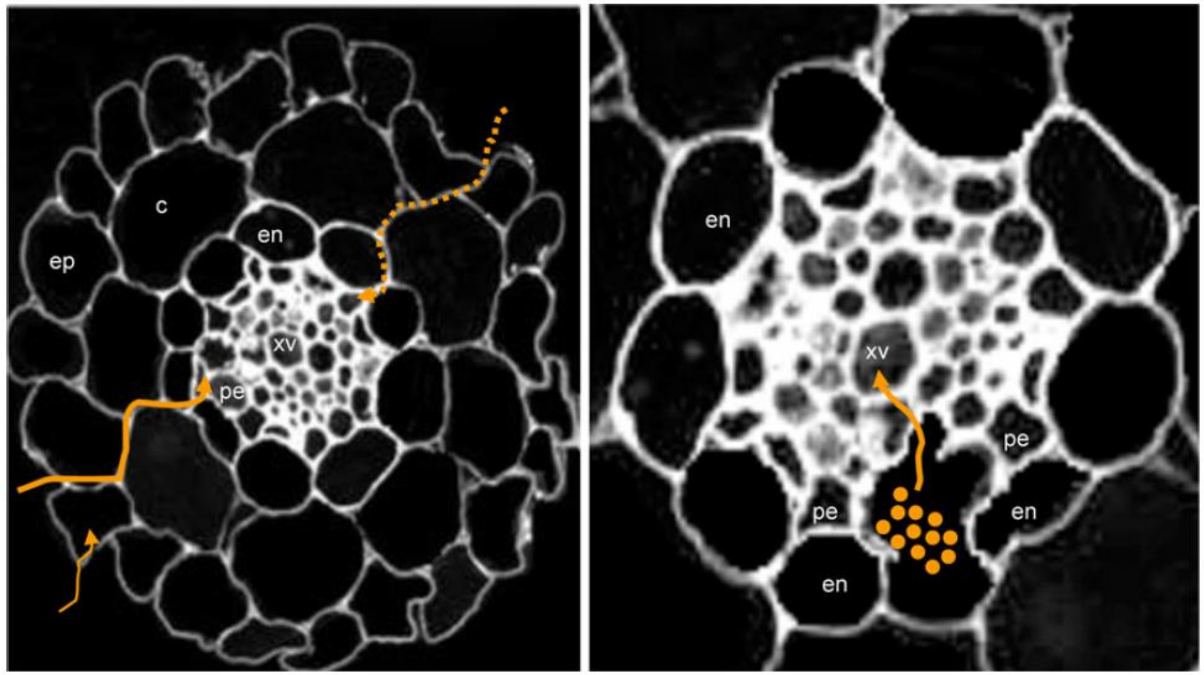
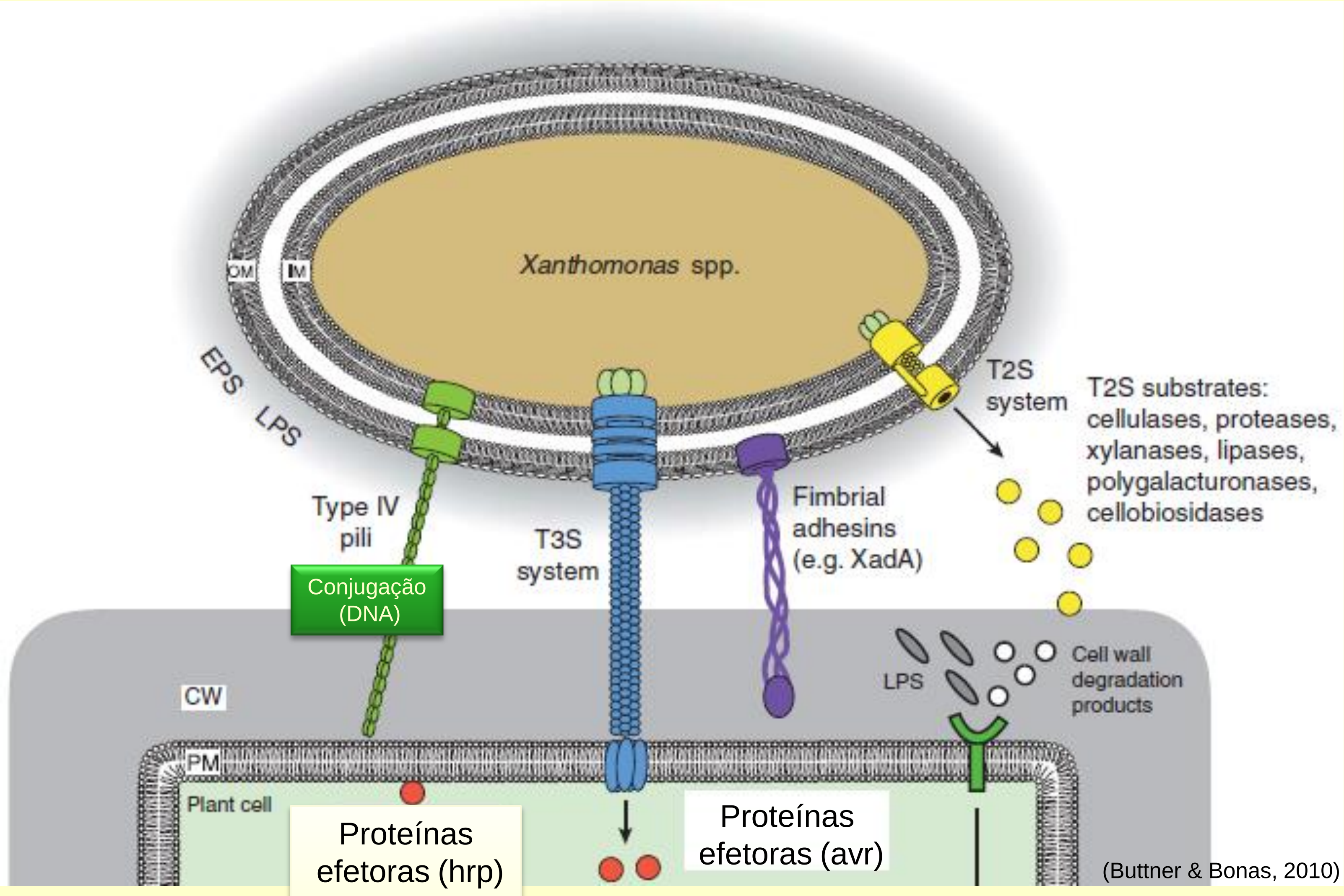


Fig. 8 Schema of *R. solanacearum* colonization of the Arabidopsis root during a compatible interaction. *R. solanacearum* exhibits two phases of infection in the root: a propagation phase (*left panel*) and a proliferation phase (*right panel*). The propagation phase occurs within the cortex (*thick solid arrow*) with bacteria principally observed in the intercellular spaces. Bacteria are also observed, albeit in a highly restricted manner, in plasmolysed epidermal cells (*thin solid arrow*). Another potential propagation route is also indicated (*dashed arrow*). In a second phase (*right panel*), when the bacteria reach the endodermal/pericycle cell junction facing the xylem pole, bacterial proliferation begins and massive invasion is observed in the xylem vessels. *ep* epidermal cell, *c* cortical cell, *en* endodermis, *pe* pericycle, *xv* xylem vessel

Digonnet et al. (2012)

Colonização bacteriana



(Buttner & Bonas, 2010)

COLONIZAÇÃO

- Como o patógeno coloniza o hospedeiro?

  relações tróficas

- Como o patógeno conquista diferentes partes do hospedeiro?

  sistemicidade / infecção localizada

- Quanto tempo demora a colonização?

  conceito de latência

Vias de distribuição de patógenos

LOCALIZADA

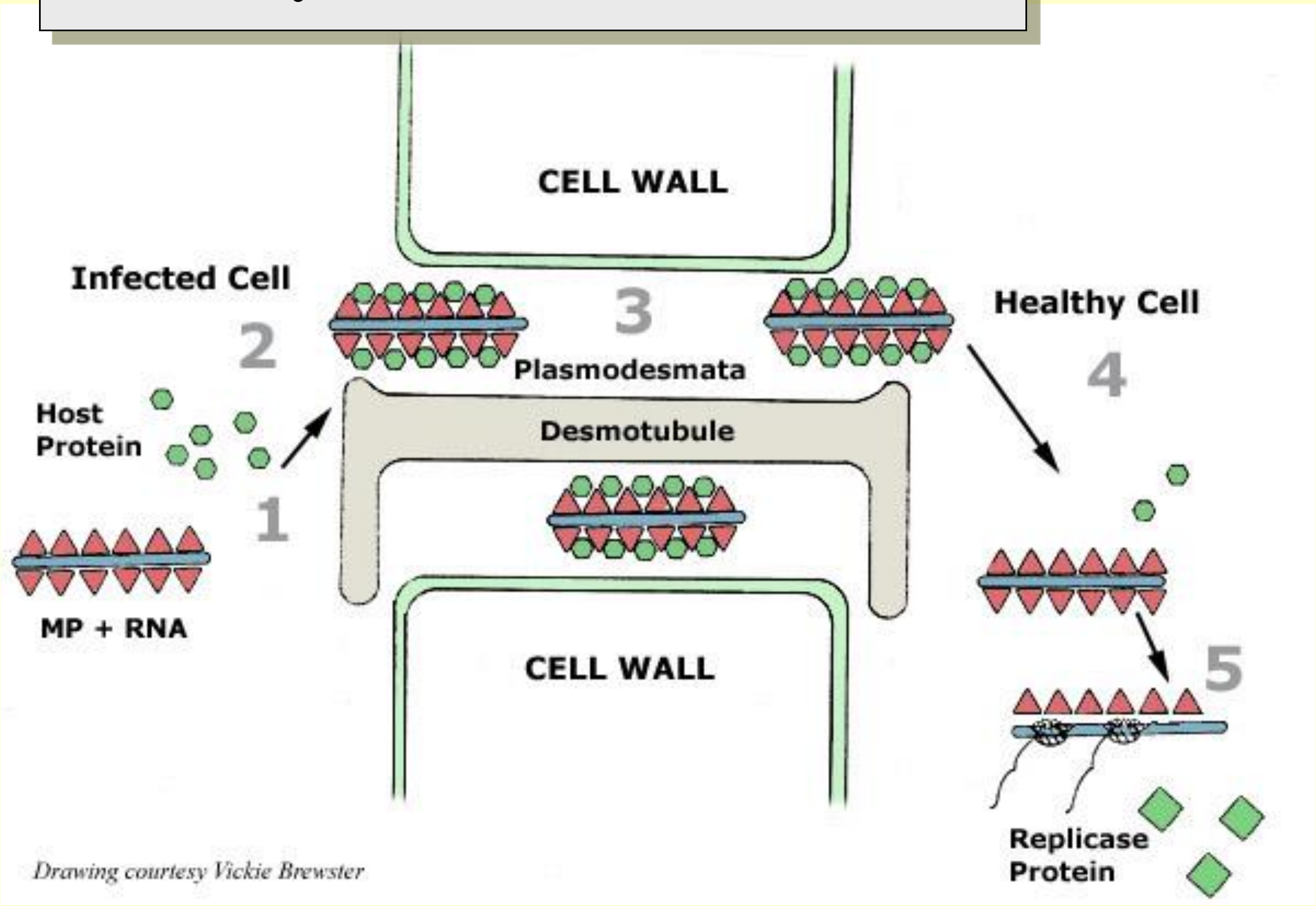
- SUBCUTICULAR – *Venturia inaequalis*, *Colletotrichum*
- INTERCELULAR – Bactérias e fungos diversos
- INTRACELULAR
  - biotróficos – *Puccinia*, vírus
  - hemibiotróficos – *Colletotrichum*
  - necrotróficos - *Colletotrichum*

SISTÊMICA

- XILEMA – *Fusarium oxysporum*, *Verticillium dahliae*, *Xylella fastidiosa, Ralstonia solanacearum*
- FLOEMA – Vírus, viróides
  Fitoplasmas
  Bactérias (Liberibacter)

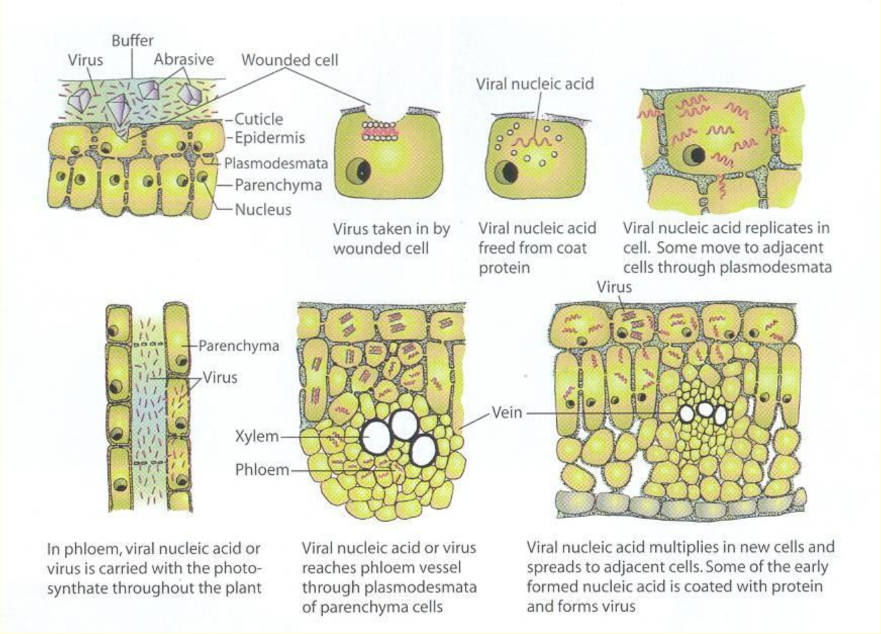
Célula a célula
Floema

Distribuição de vírus célula a célula

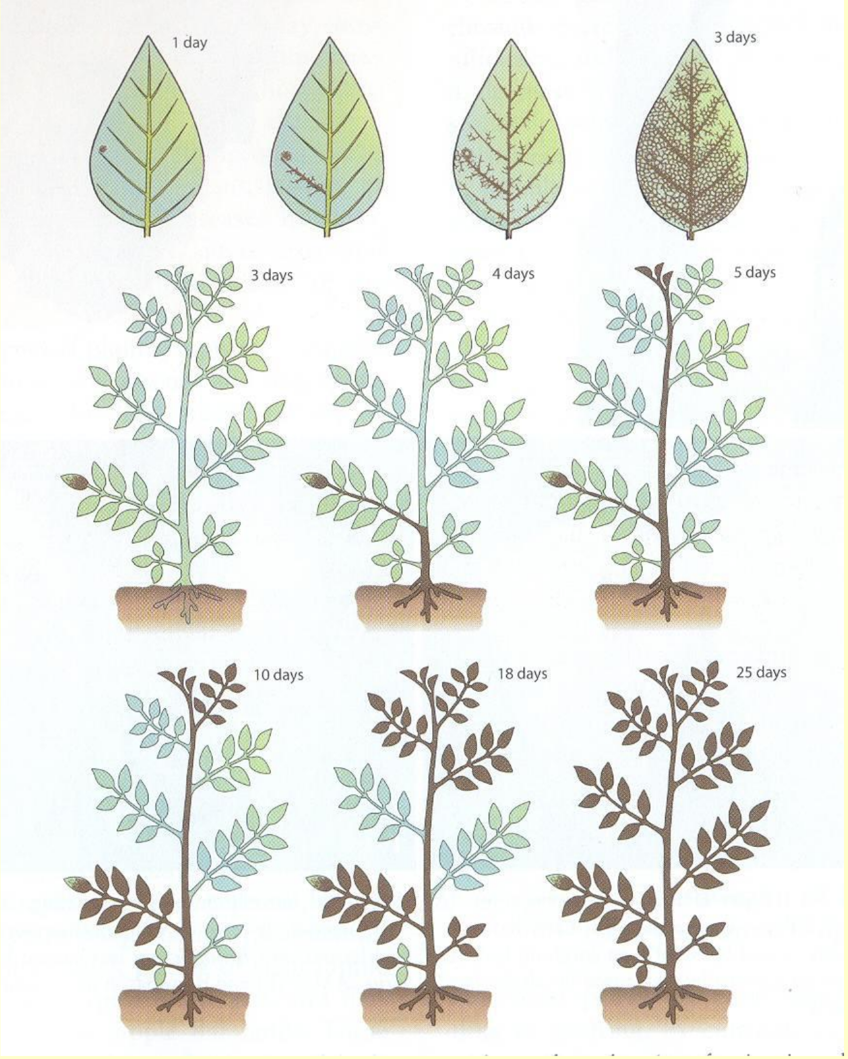


MP=proteína de movimento (proteínas do hospedeiro e/ou codificadas pelo vírus)

Distribuição sistêmica de vírus e viróides



Vírus como TMV requerem o capsídeo para movimento pelo floema. Mutantes que não formam capsídeo conseguem se distribuir localizadamente, mas não a longas distâncias. Geminivírus podem requerer ou não a proteína da capa protéica no transporte pelo floema. (Carrington et al., 1996)



Modelo de distribuição sistêmica de vírus em plantas

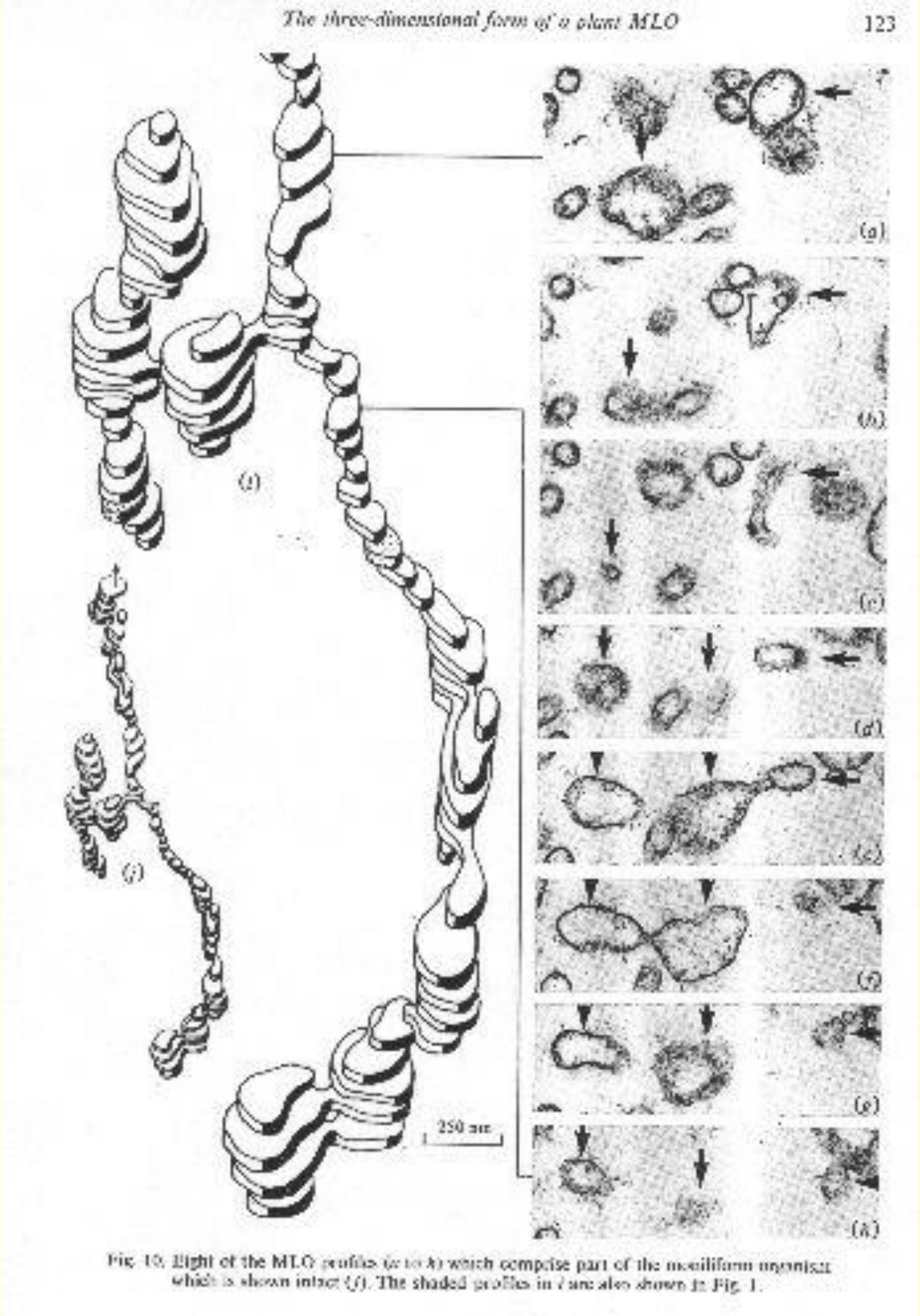
(Agrios, 2005)

Distribuição sistêmica de fitoplasmas

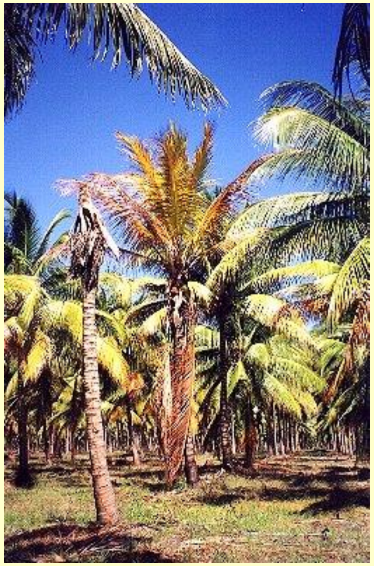
Procariotos sem parede celular – pleomórficos
Habitantes do floema
Transmitidos por insetos (cigarrinhas)
Relacionados aos "amarelos"
Relacionados a desequilíbrios hormonais
Distribuídos desuniformemente nas plantas

Fitoplasma do milho
Bushy stunt phytoplasma

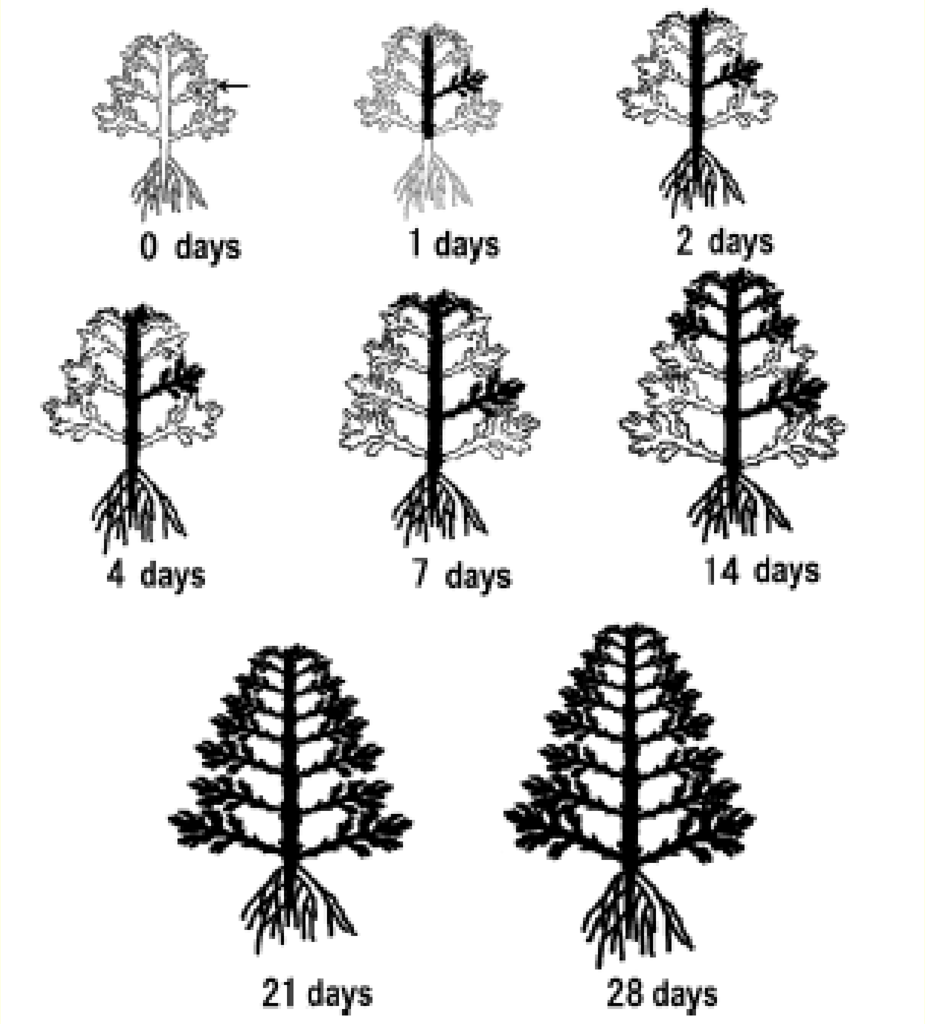
Dalbulus maidis



Distribuição sistêmica de fitoplasmas



Distribuição sistêmica de fitoplasmas



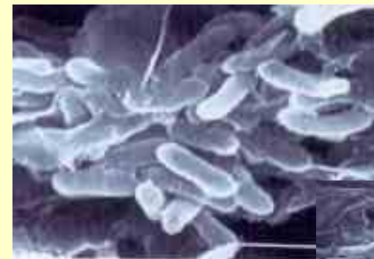
Representação da migração do onion yellow phytoplasma em crisântemo (*Chrysanthemum coronarium*), baseado em dados experimentais com nested PCR. Áreas escuras denotam localização do patógeno. A seta no dia zero indica o local da inoculação com vetor.

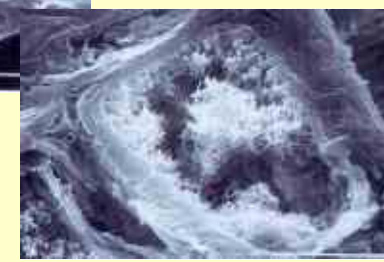
Wei et al. Phytopathology 94:244-250, 2004

Patógenos vasculares

Verticillium dahliae em xilema de tomate

Clorose Variegada dos citros





Xylella fastidiosa **em xilema de citros e de cafeeiro**

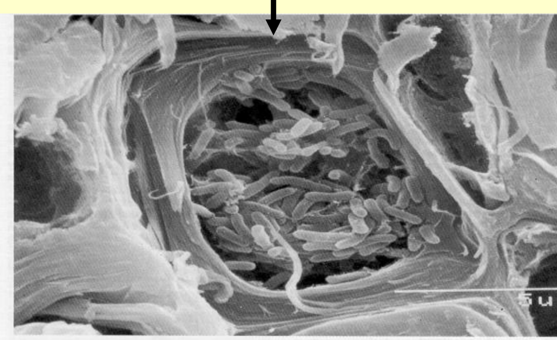
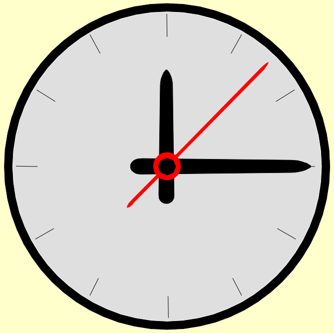


Fig. 2. *Xylella fastidiosa* bacteria in a cross-section of petiole xylem vessel affected by coffee leaf scorch as seen by scanning electron microscopy.

O conceito de latência



Período de latência – deposição à reprodução

Período de incubação – deposição aos sintomas

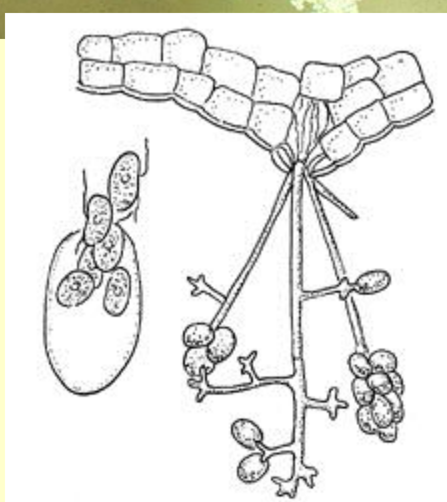
Períodos latentes em quatro variedades de cevada inoculadas com *Puccinia hordei*

	Folha número				
	1	4	7	9-jovem	9-velha
L94	100	106	113	117	109
Volla	104	113	122	142	135
Julia	110	125	141	182	166
Vada	123	140	157	233	201

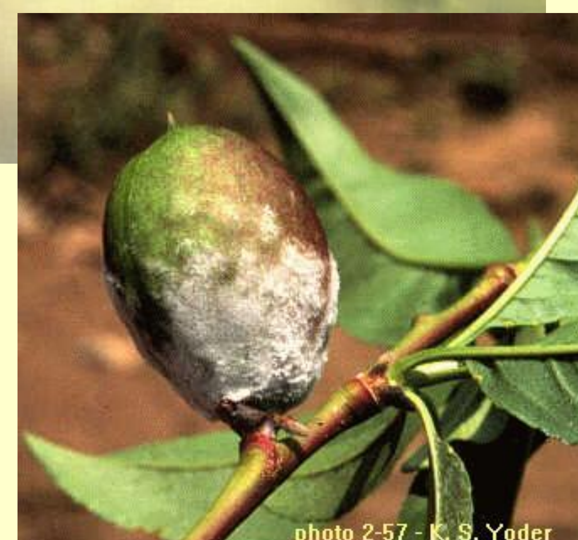
Latência ≠ quiescência

Patógenos biotróficos - Reprodução

Míldio da videira



Oídio em nectarina

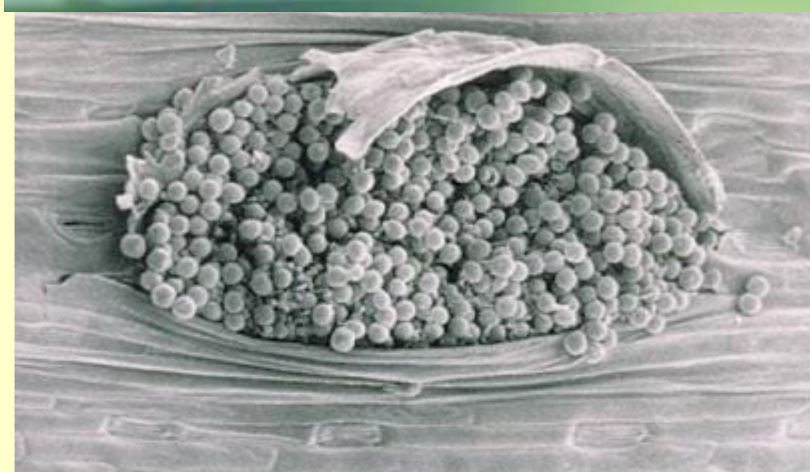


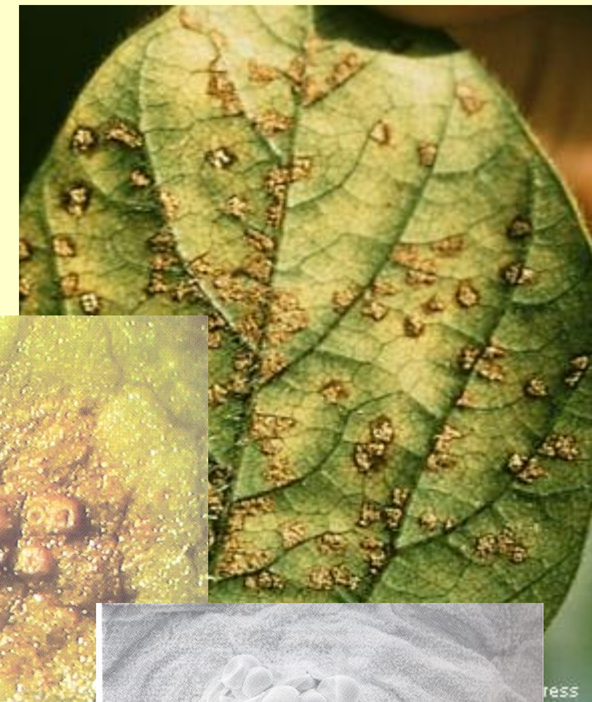
Patógenos biotróficos - reprodução

Ferrugens

Puccinia graminis

Phakopsora pachyrhizi





Patógenos hemibiotróficos

Patógenos vasculares

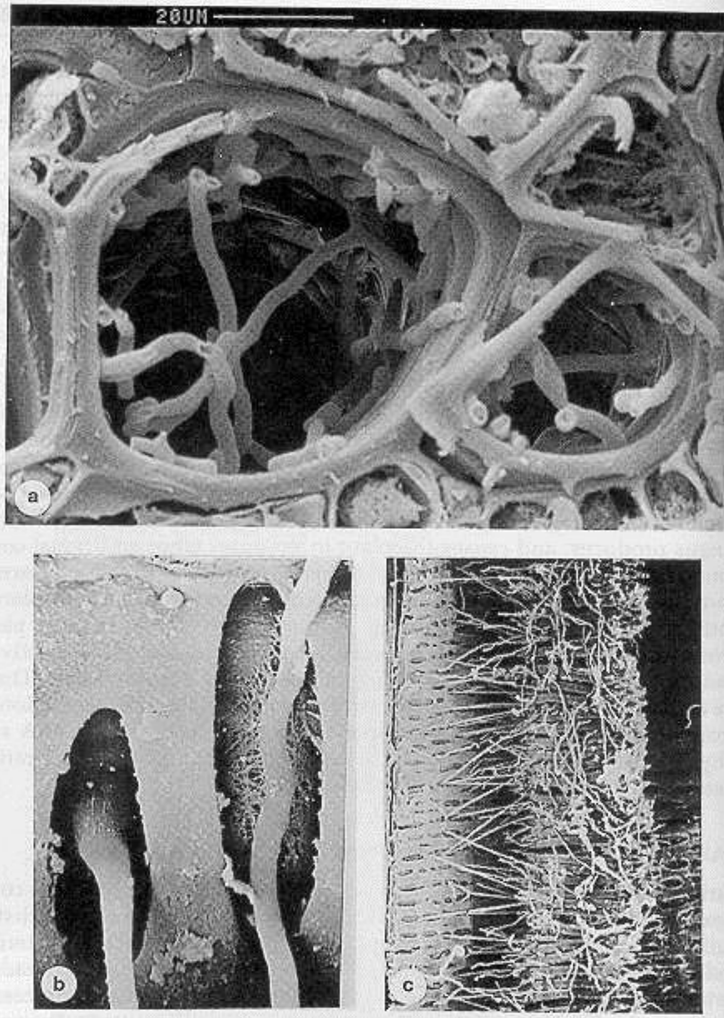
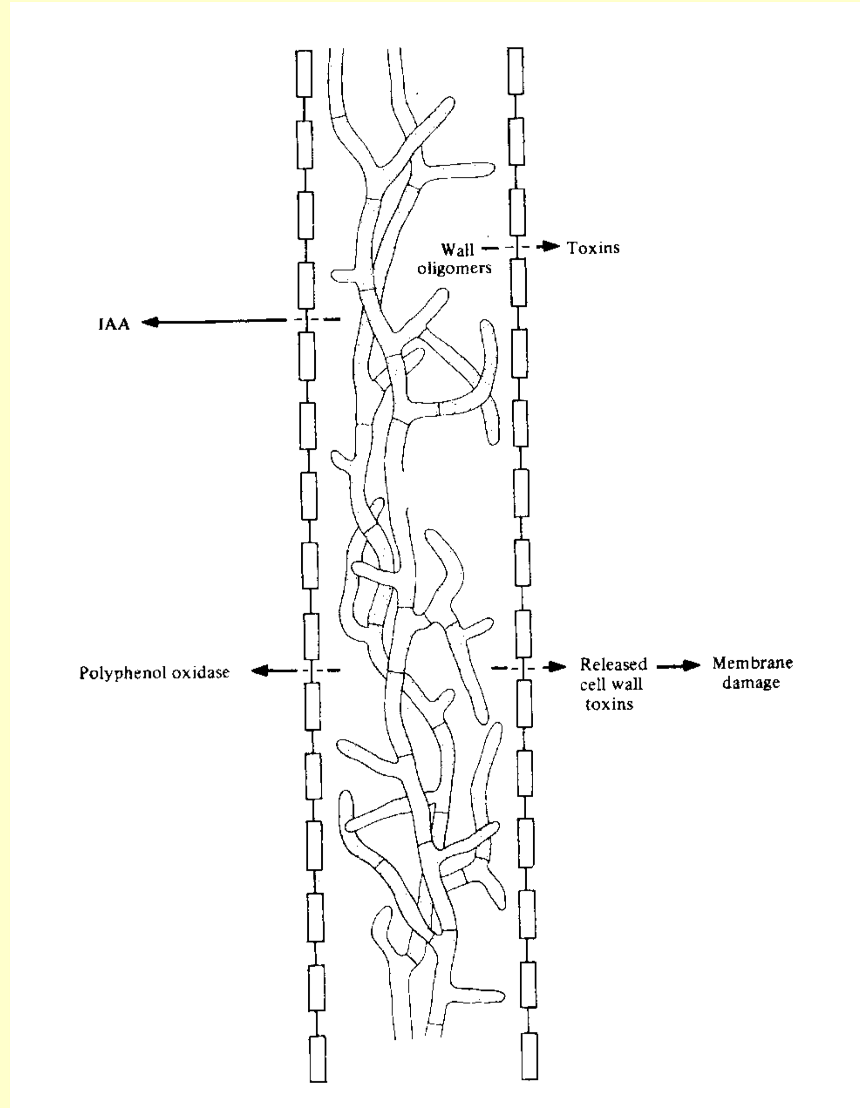


Fig. 4.10 Scanning electron micrographs of plants infected by vascular wilt pathogenic fungi. (a) Hyphae of *Verticillium albo-atrum* within vessels (transverse section) of hop cv. Northdown (x1060). Reproduced courtesy of J. H. Carder, IHR East Malling. (b) *Fusarium oxysporum* f. sp. *cubense* breaching pit membranes in banana root xylem vessels showing enzymic degradation. (c) Longitudinal section of banana root xylem vessels colonised by *Fusarium oxysporum* f. sp. *cubense*. (b, c) Reproduced from Pegg (1985), courtesy of Prof. Pegg and Cambridge University Press.



Patógenos vasculares

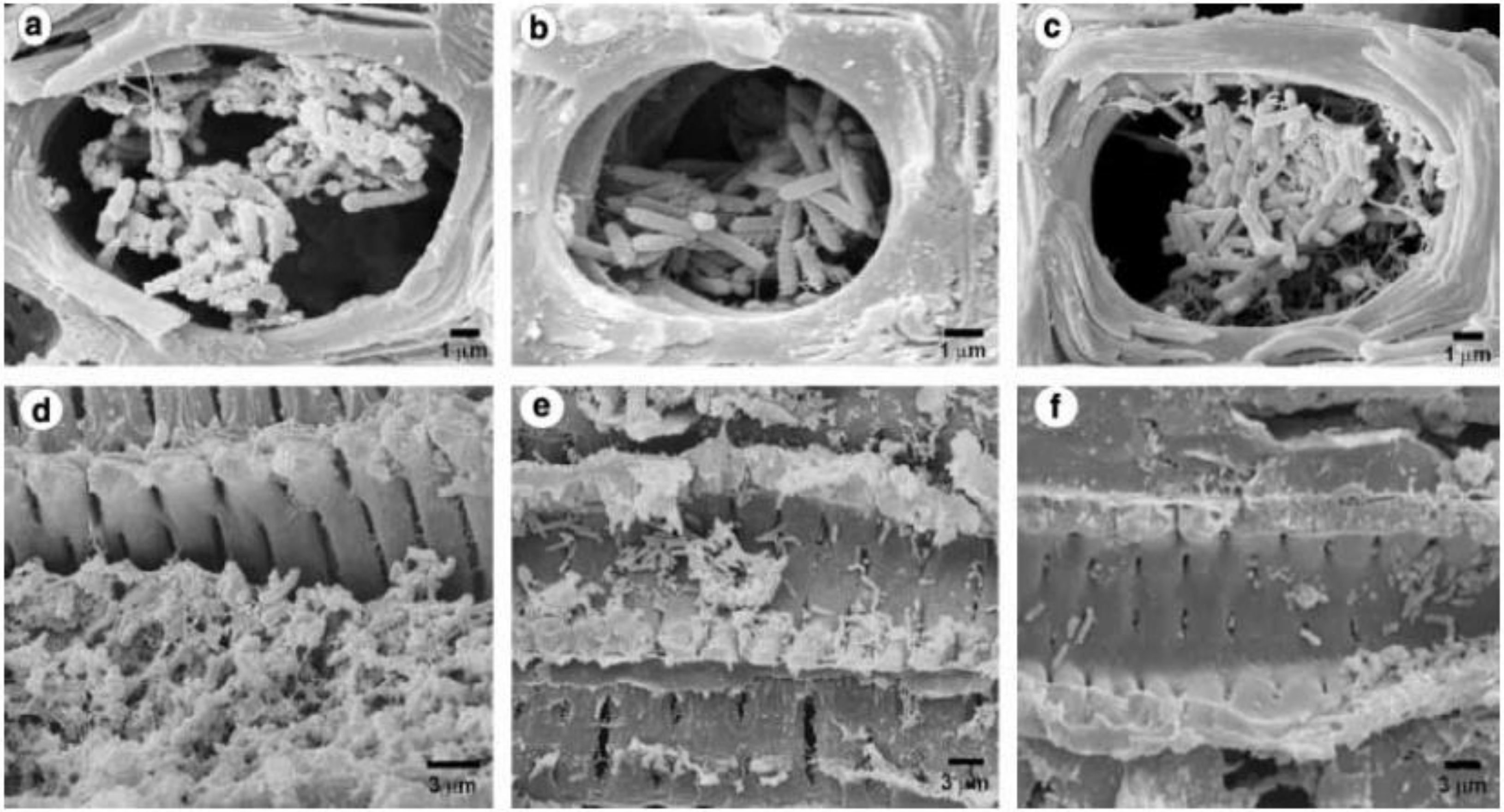


Fig. 4 Scanning electron micrography showing morphological characteristics of *Xylella fastidiosa* and details of its pattern of xylem vessel colonization. a = plum, b = coffee and c = citrus. The predominant colonized vessel types for each host is seen. d = spiral vessels in plum, e = reticulate vessels in coffee and f = pitted vessels in citrus

Alves et al. J. Phytopathology 152, 291–297 (2004)

Patógenos necrotróficos

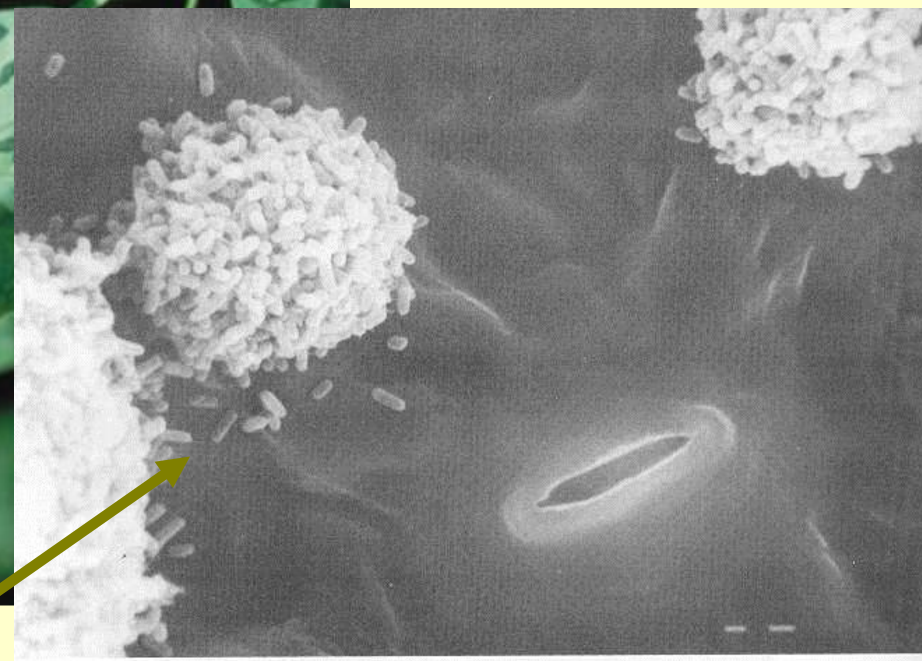
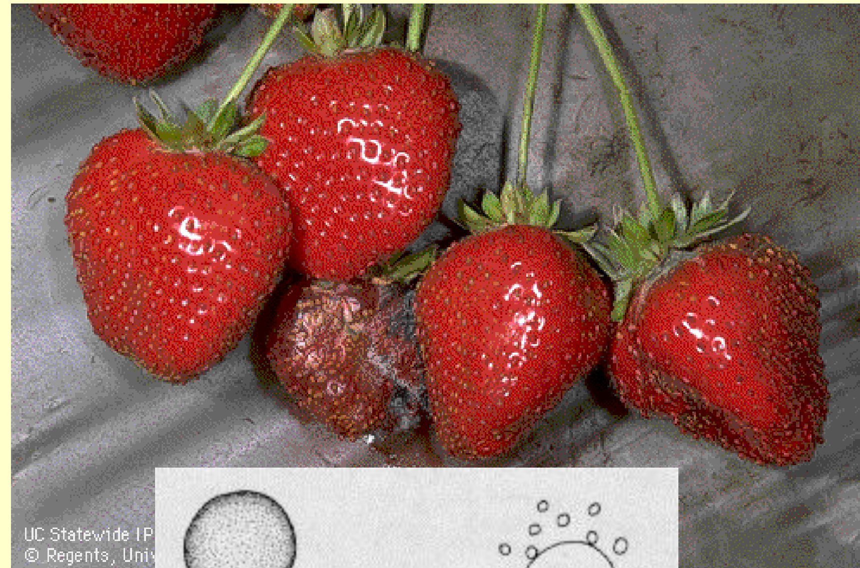
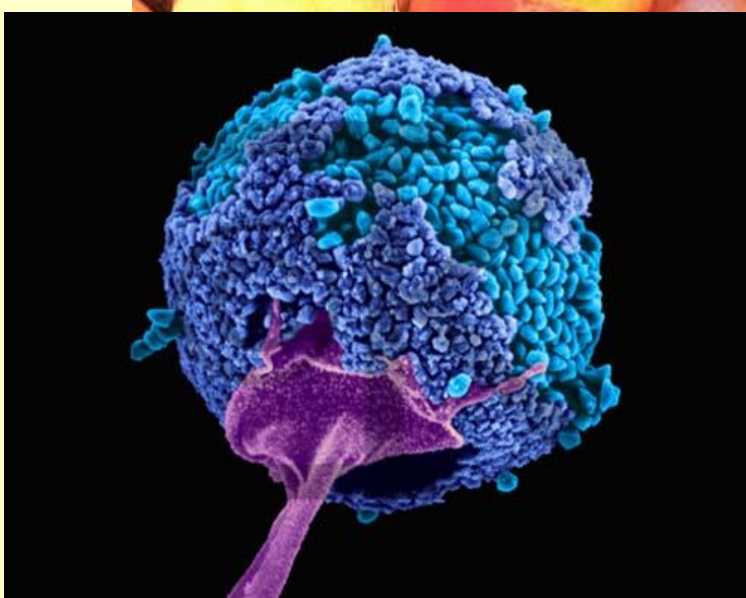


FIGURE 12-36 *Pseudomonas syringae* pv. *morsprunorum* exuding from stomata of infected cherry leaves. [Photo courtesy Roos and Hattingh (1983), *Phytopathol. Z.* 108, 18–25.]

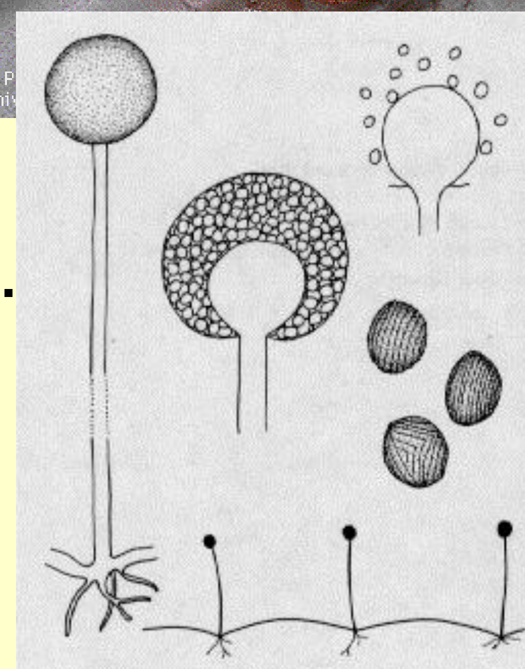
Exsudação de *Pseudomonas syringae* em cerejeiras

Patógenos necrotróficos

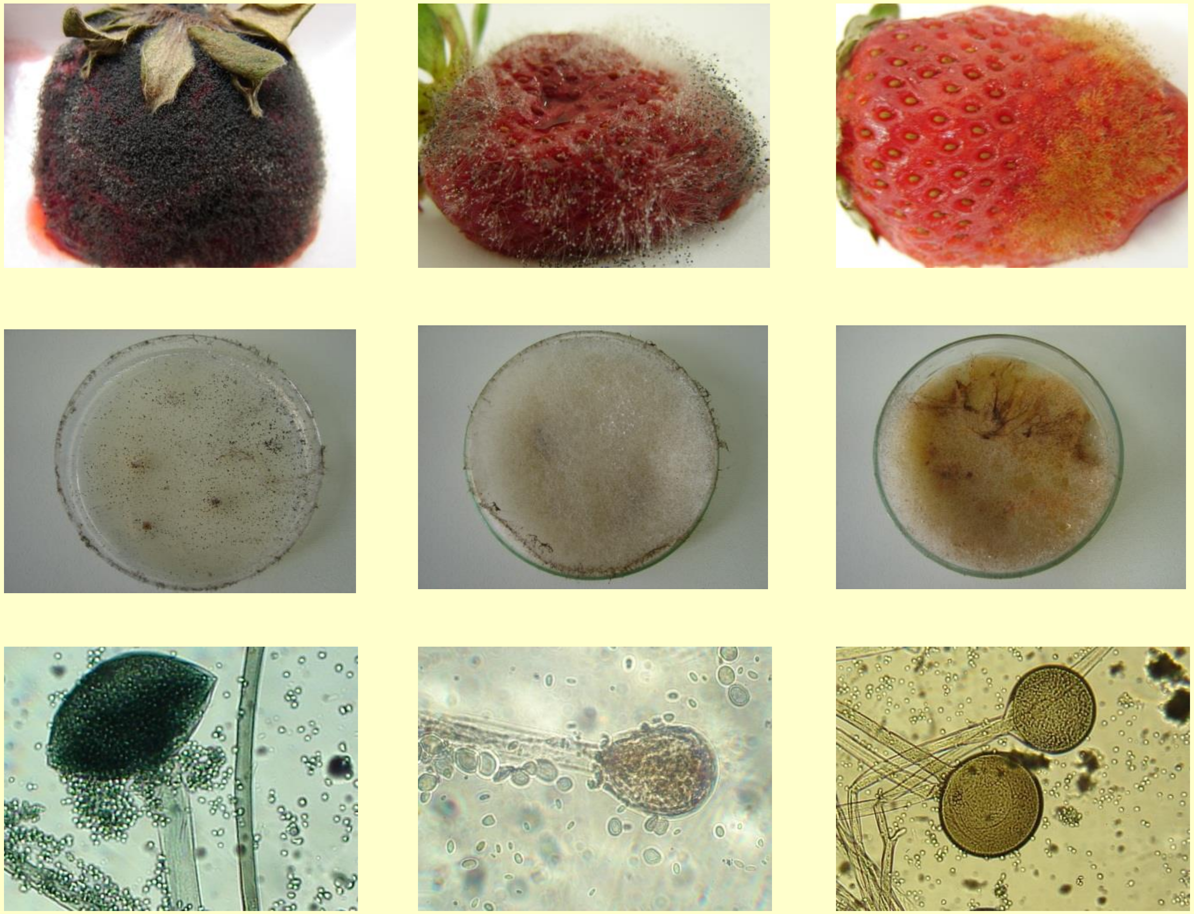




Rhizopus sp.

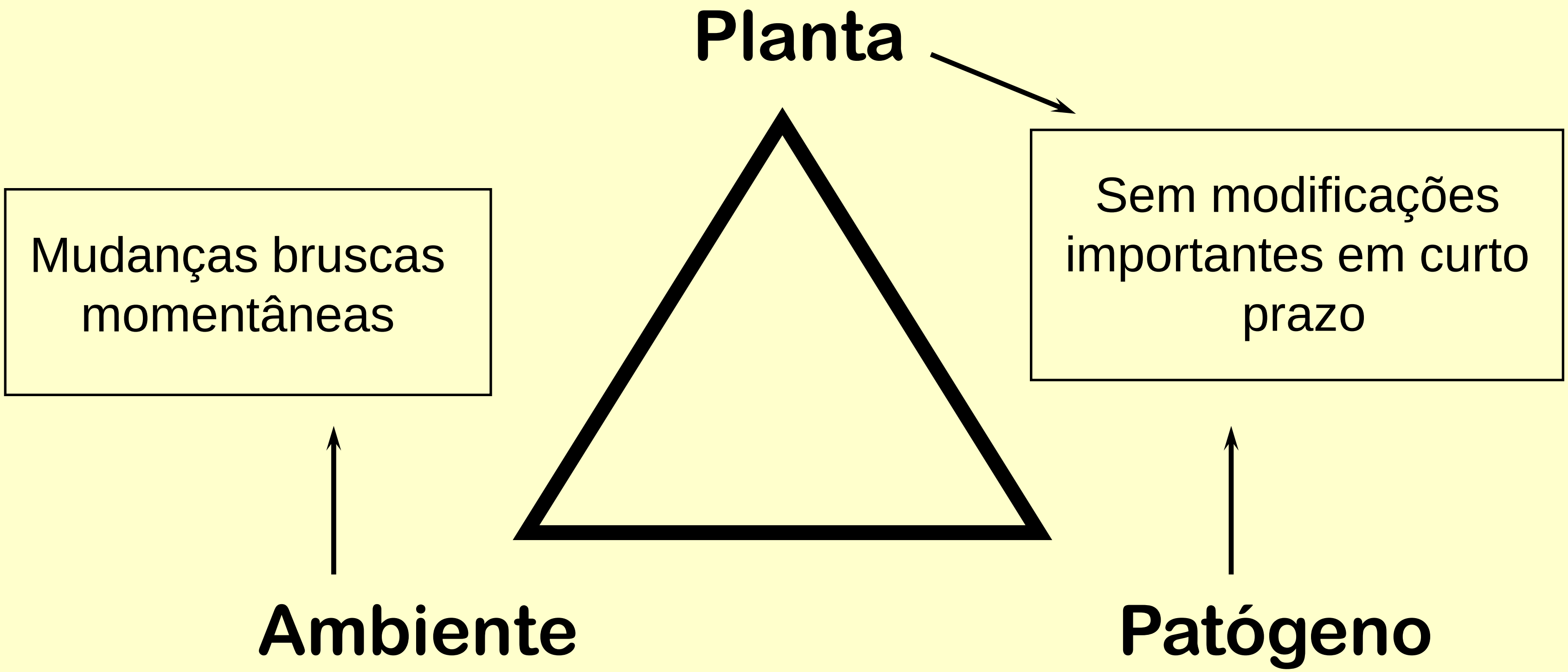


Patógenos necrotróficos

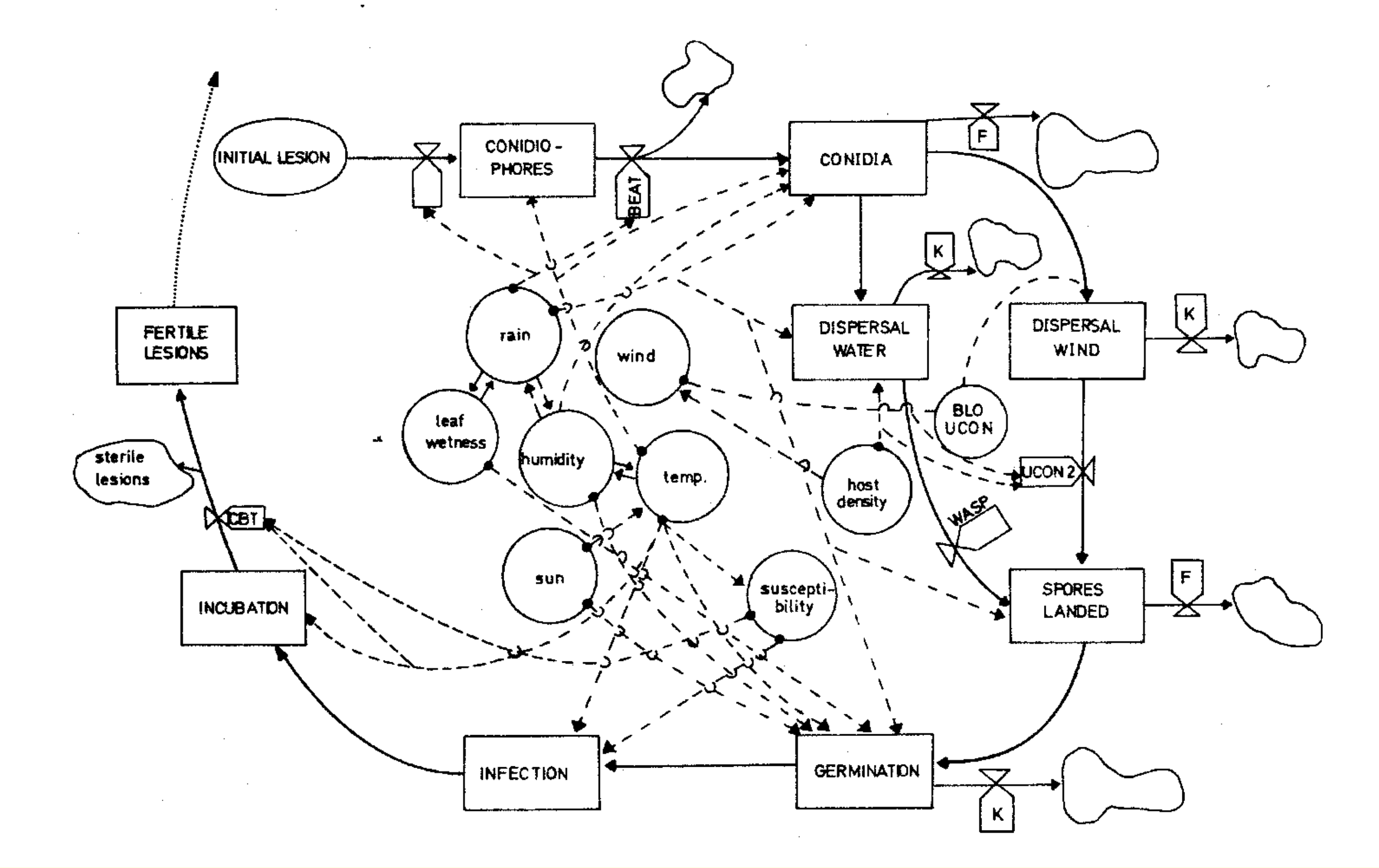


Podridões mole em morangos coletados em produtor de Campinas (Martins, 2007)

Ambiente e Doença

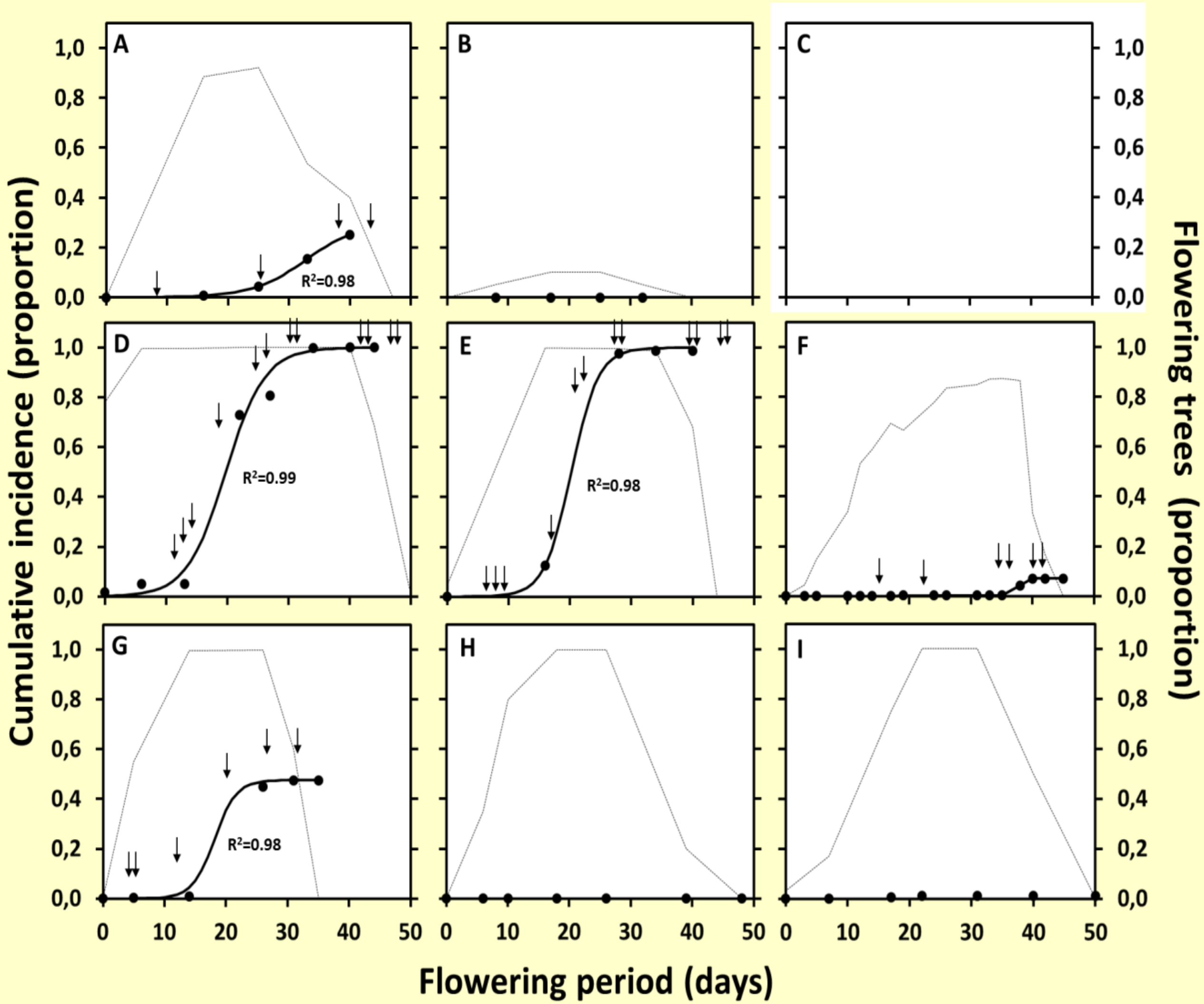


Ambiente e Doença



Ambiente e Doença

Figure 2. Cumulative incidence (proportion) of trees with symptomatic flowers and proportion of flowering trees (dotted line) in three orchards during the flowering period in São Paulo State, Brazil, in 2008 (A, B, C), 2009 (D, E, F) and 2010 (G, H, I) for area 1 (A, D, G), 2 (B, E, H) and 3 (C, F, I). Solid lines indicate the logistic model fitted to postbloom fruit drop progress. Arrows indicate rainfall (> 10mm). (Silva, 2011)



Ambiente e Doença

Ambiente e Doença

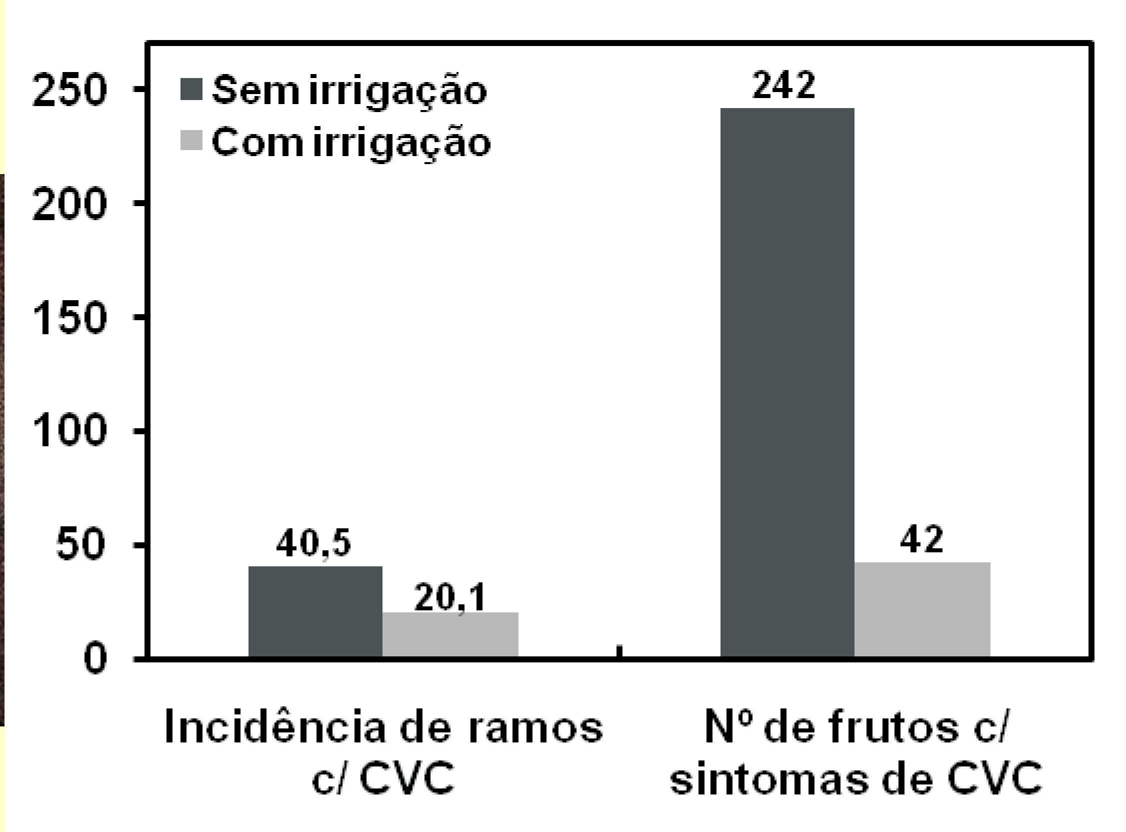


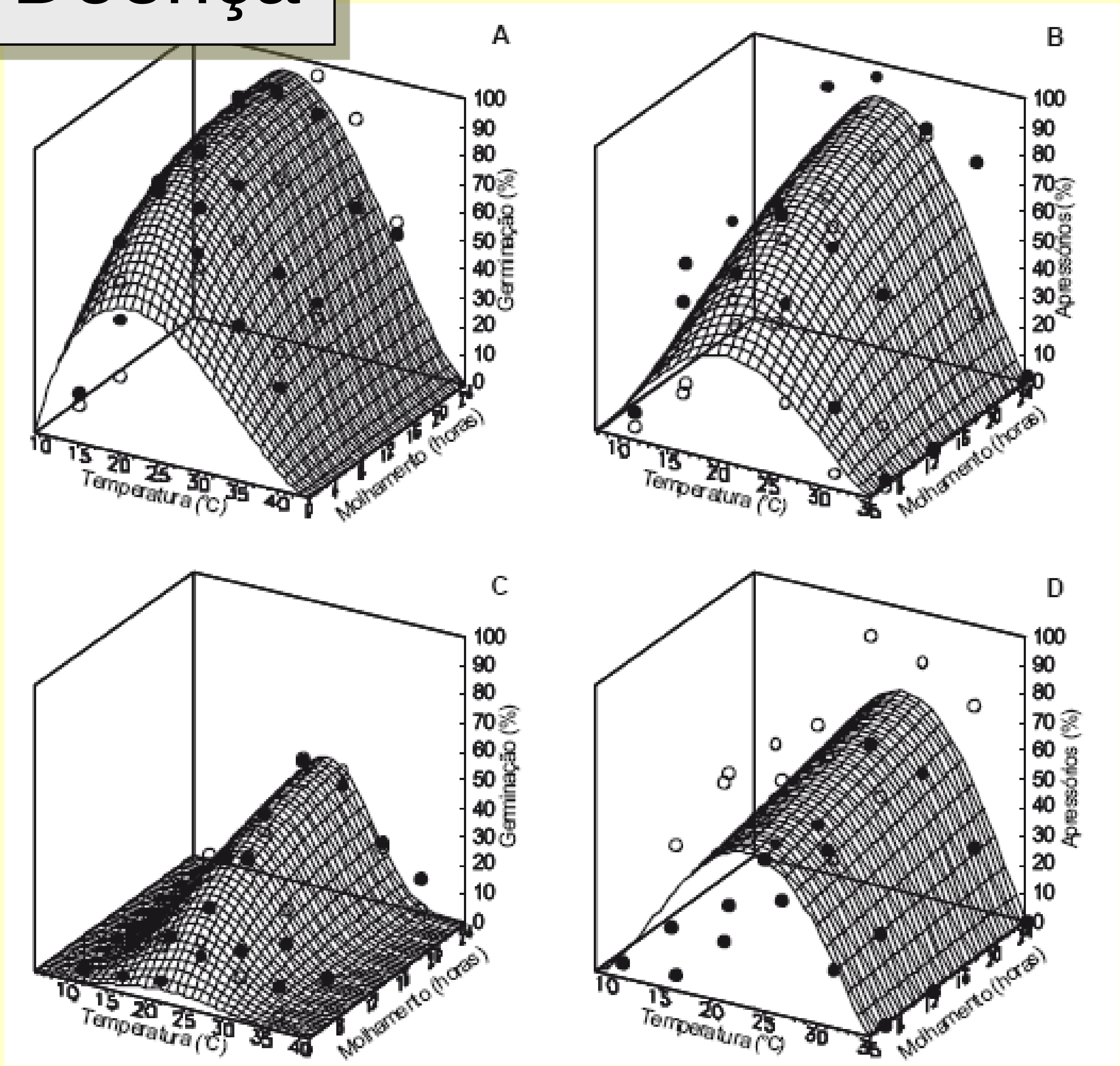
Figura 7.1 – Incidência (% de ramos com sintomas) e número de frutos com sintomas de CVC (ø< 50 mm) em plantas de laranjeira 'Natal' enxertadas em limoeiro 'Cravo' inoculadas com *Xylella fastidiosa* 10 meses após o plantio (março 1999). Resultados representam a média por planta das safras 2006 a 2008 (Gonçalves, 2010).

Ambiente e Doença

Antracnose da goiaba

C. gloeosporioides

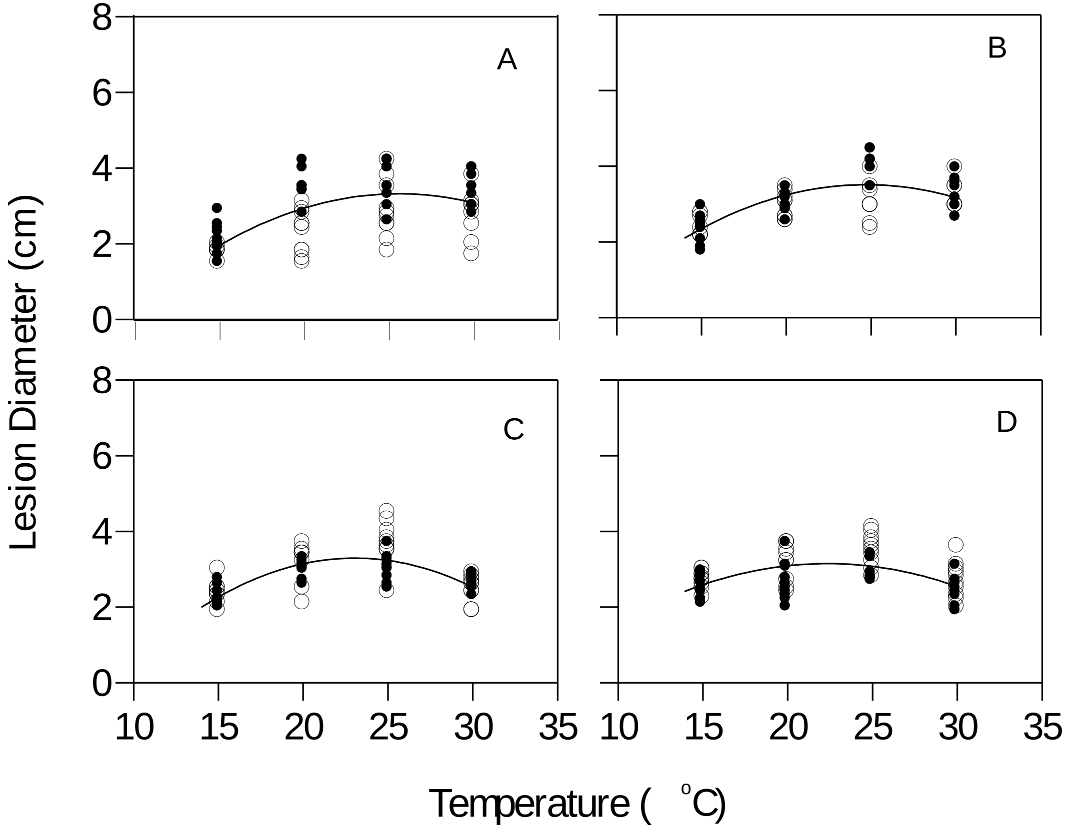
C. acutatum



Ambiente e Doença

Antracnose da goiaba

C. gloeosporioides *C. acutatum*



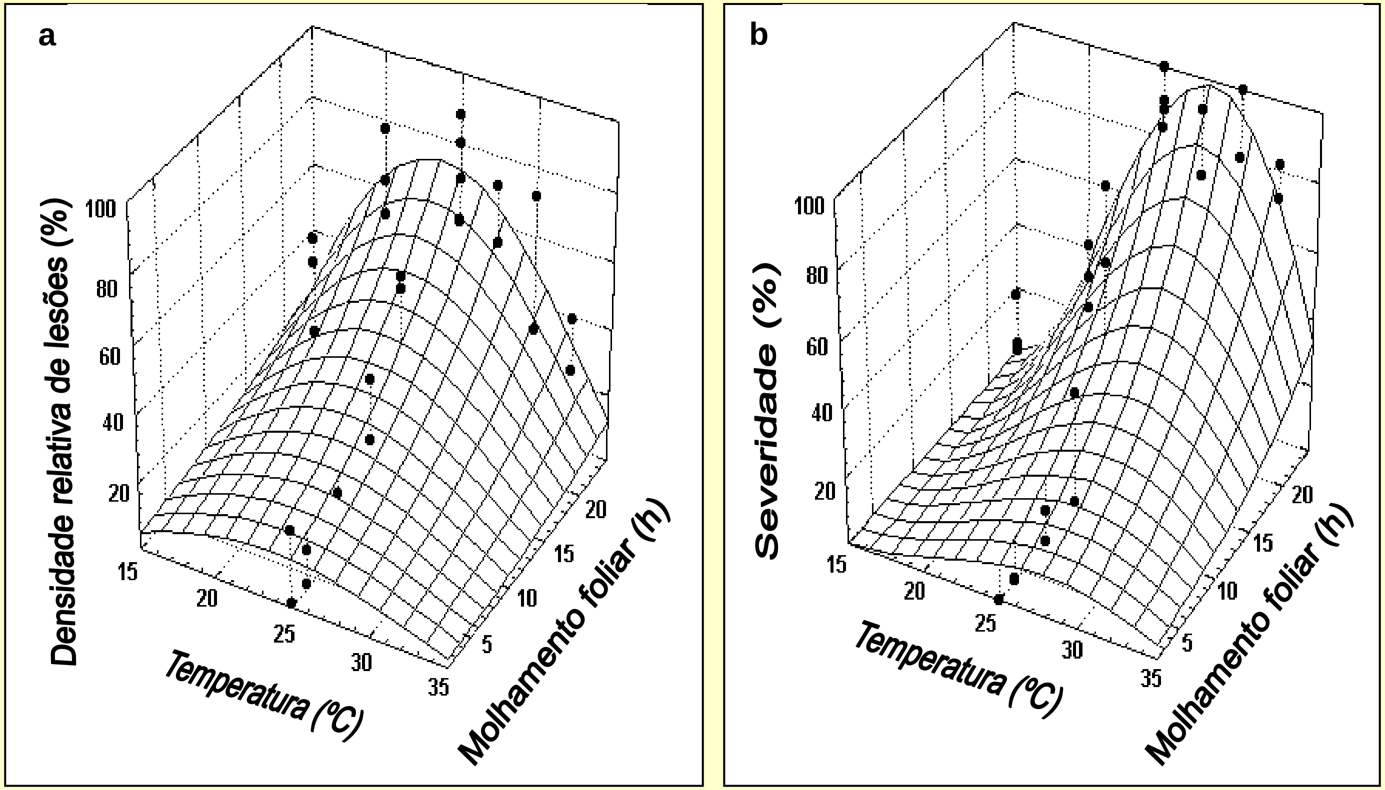
Período de molhamento

12 h

24 h

Ambiente e Doença

Alternaria helianthi - girassol



Ambiente e Doença

Temperatura e Umidade

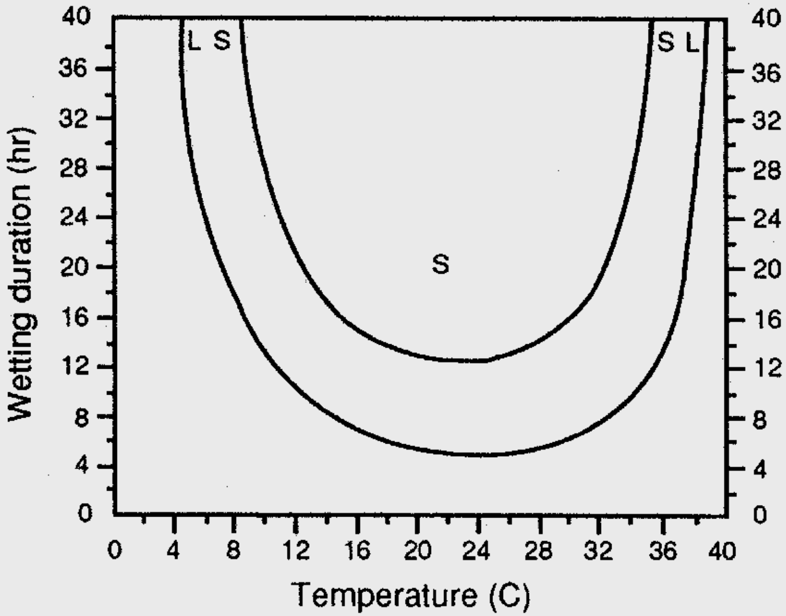


FIGURE 7-7 Leaf wetness and temperature requirements for the leaf-spotting fungus *Alternaria mali* to cause light (L) or severe (S) infection. [From Filajdić and Sutton (1992), *Phytopathology* 82, 1279–1283.]

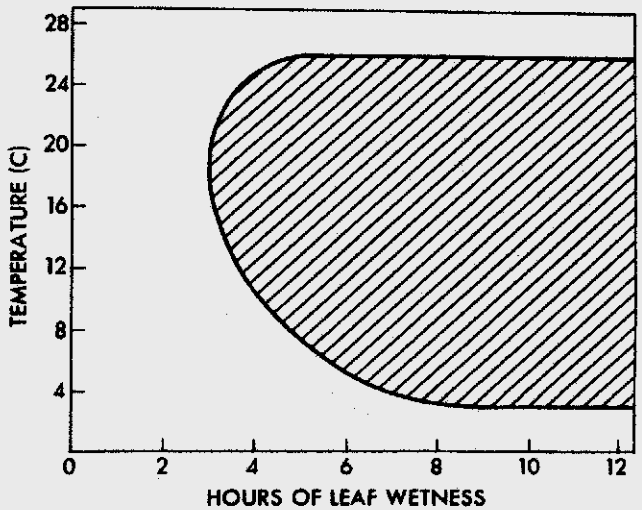


FIGURE 7-8 In the cedar-apple rust caused by the fungus *Gymnosporangium juniperi-virginianae*, formation of basidiospores occurs when the temperature–leaf wetness point is at the transition line between the clear and shaded area of the diagram. If the temperature–leaf wetness point is within the shaded area, spore germination has occurred and infection is likely. [From Seem and Russo (1984), *Plant Dis.* 68, 656–660.]

Ambiente e doença

Câmaras de crescimento de plantas

Painel de controle com programação de:

temperatura, luz
umidade relativa

Variáveis climáticas
-como medir-

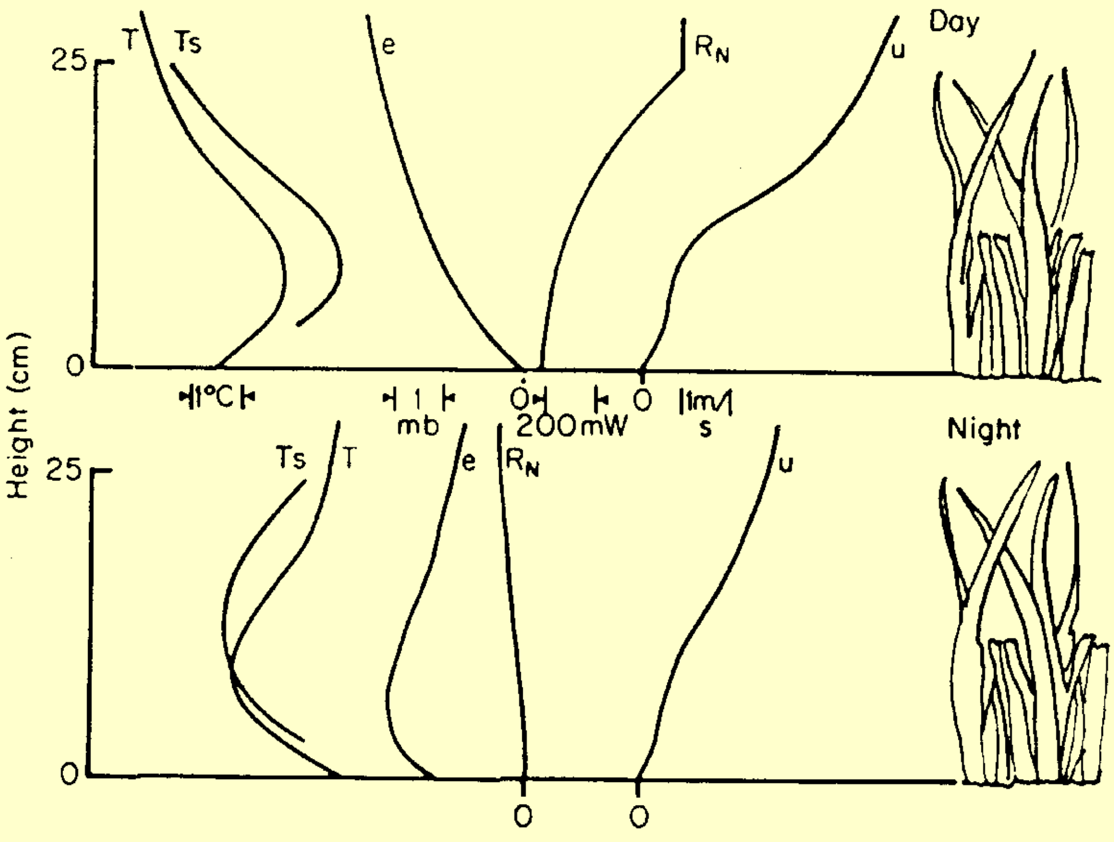


Figure 4.1. Idealized day and night vertical gradients of selected environmental variables in the canopy of a 25-cm tall grass crop for air temperature (T), leaf surface temperature (T_s) vapor pressure (e), radiation (R_N), and wind speed (u) (adapted from Burrage, 1978).

Ambiente e doença

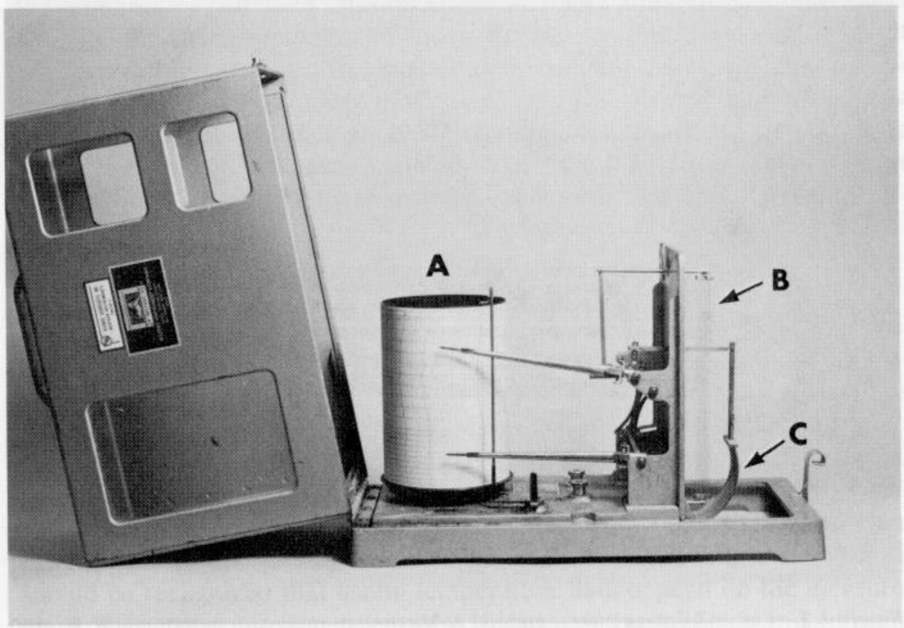


Figure 4.3. Hygrothermograph with deformation (filled-system) thermometer (C) and hair hygrometer (B). Changes in sensing elements are translated mechanically to recording pens on rotating strip chart recorder (A).

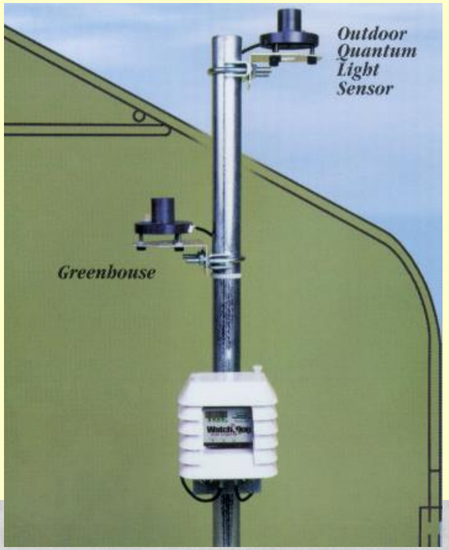


Figure 4.14. Instruments for measuring direct and diffuse solar radiation. (*a*) Eppley pyranometer (from Sutton et al., 1984; used with permission). (*b*) Silicon photocell pyranometer (courtesy LI-COR, Inc., Lincoln, NE).

Termohigrógrafo

&

piranômetro

Ambiente e doença

Microestação meteorológica