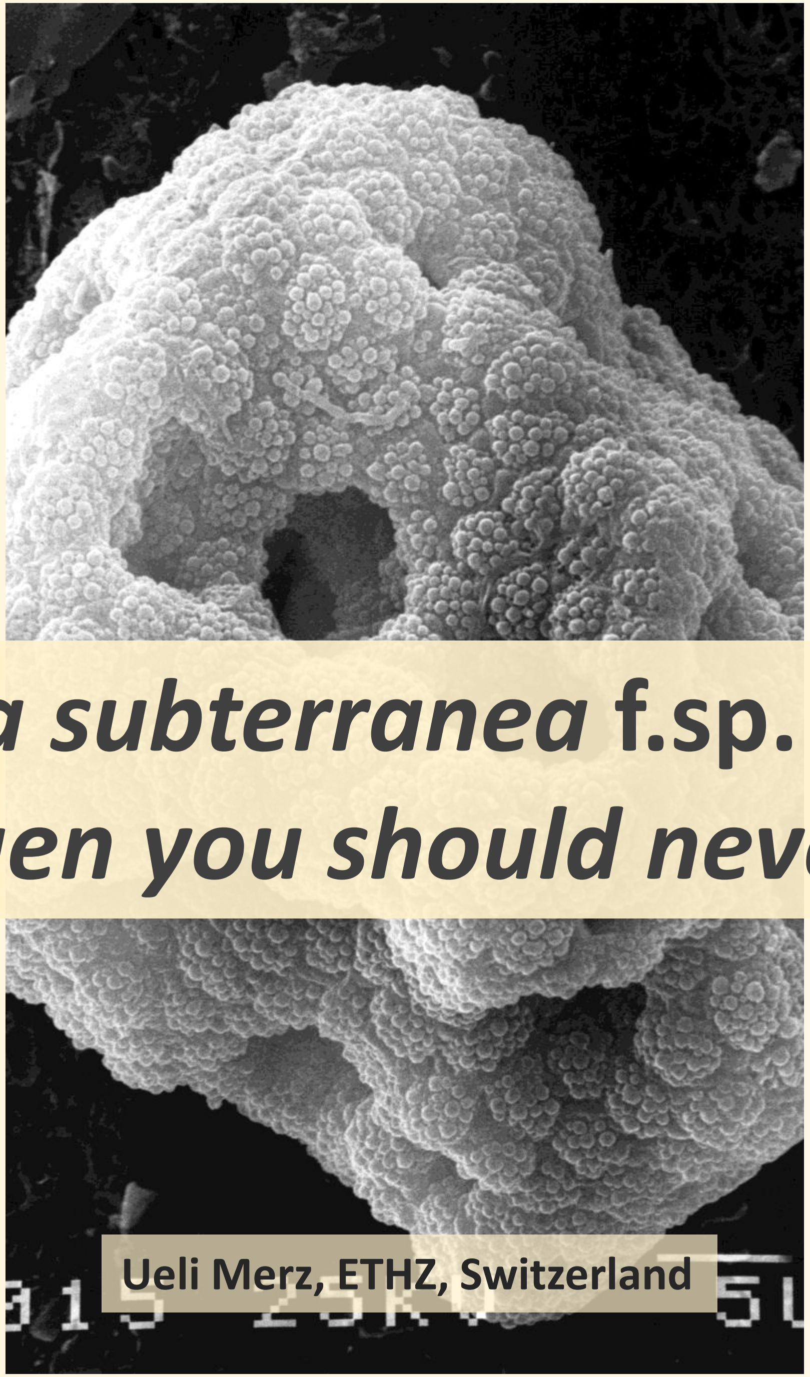
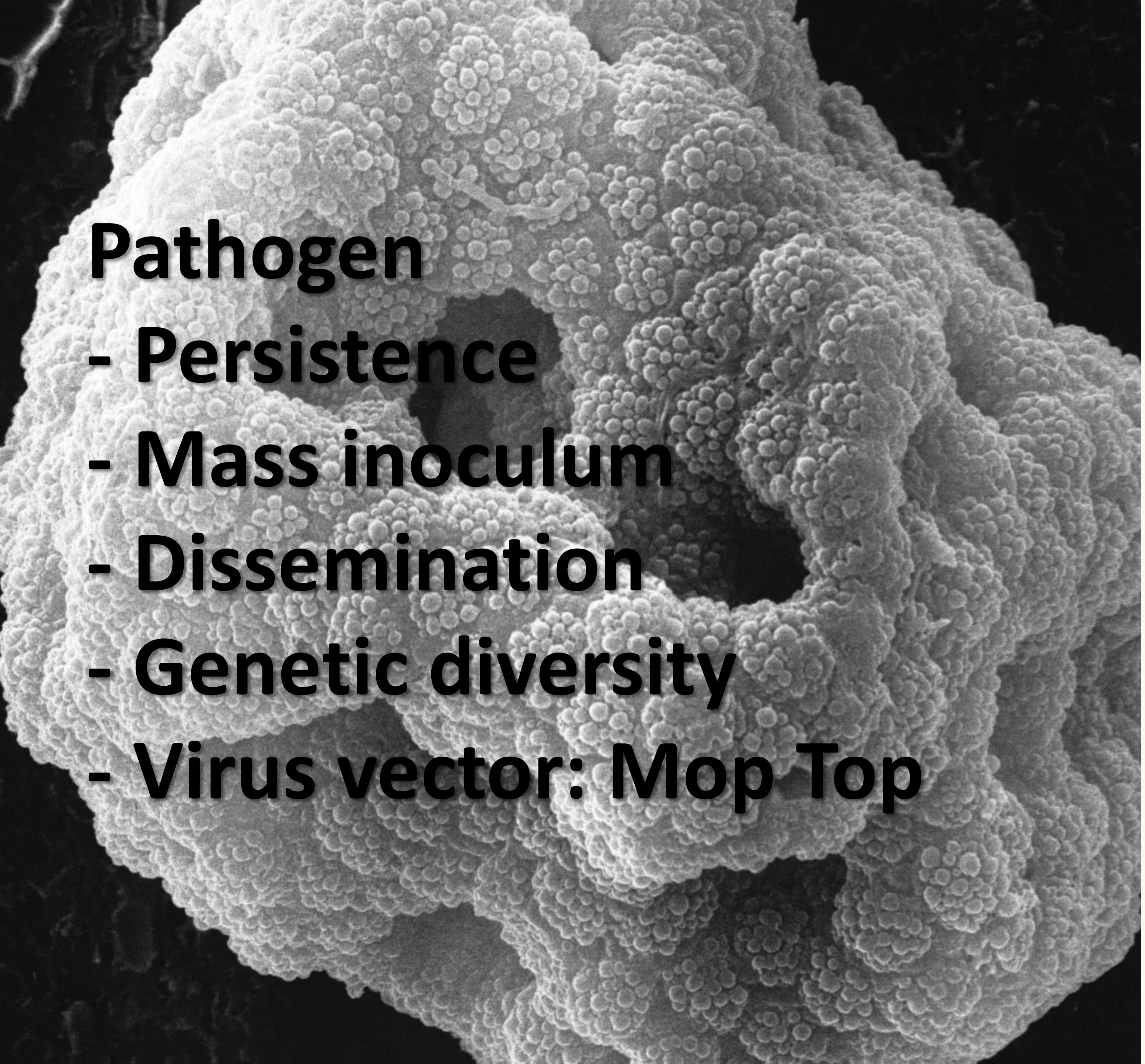
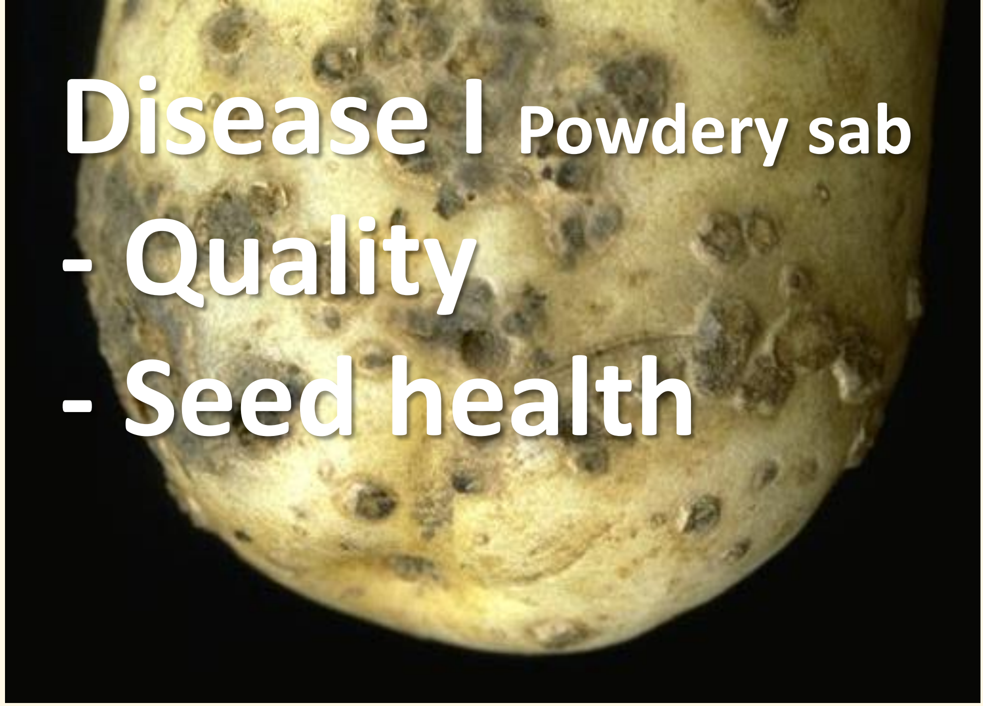


Spongospora subterranea f.sp. *subterranea*: *A pathogen you should never ignore!*

Ueli Merz, ETHZ, Switzerland


Pathogen
- Persistence
- Mass inoculum
- Dissemination
- Genetic diversity
- Virus vector: Mop Top


Disease I Powdery sab
- Quality
- Seed health

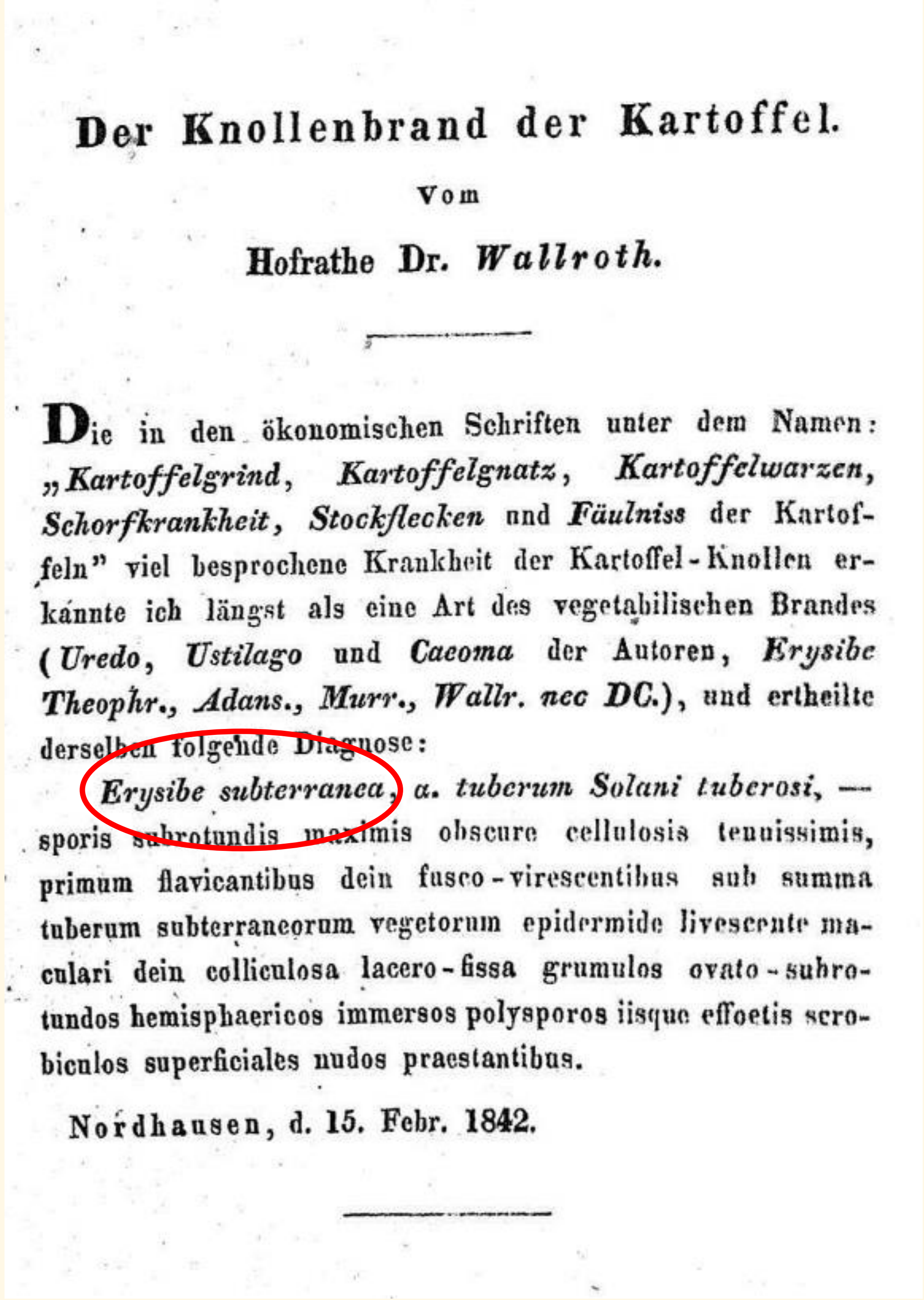

Disease II Root galls
- Stealth soil cont.
- Impact on yield
due to root hyperplasia

Spongospora subterranea has a long history in agriculture

It was 1842 when Wallroth presented his findings on a disease of potato tubers - ‘Der Knollenbrand der Kartoffel’- to a scientific audience in Germany.

This is the very first scientific document on the pathogen.

He named the pathogen ‘*Erysibe subterranea*’, and observed that the disease was well-known among farmers in Germany (Thuringia), called *Kartoffelwarzen”.



Der Knollenbrand der Kartoffel.

Vom

Hofrathe Dr. *Wallroth.*

Die in den ökonomischen Schriften unter dem Namen: „*Kartoffelgrind*, *Kartoffelgnatz*, *Kartoffelwarzen*, *Schorfkrankheit*, *Stockflecken* und *Fäulniss* der Kartoffeln“ viel besprochene Krankheit der Kartoffel-Knollen erkannte ich längst als eine Art des vegetabilischen Brandes (*Uredo*, *Ustilago* und *Caeoma* der Autoren, *Erysibe Theophr.*, *Adans.*, *Murr.*, *Wallr. nec DC.*), und ertheilte derselben folgende Diagnose:

Erysibe subterranea, *a. tuberum Solani tuberosi*, — sporis subrotundis maximis obscure cellulosis tenuissimis, primum flavicantibus dein fusco-virescentibus sub summa tuberum subterraneorum vegetorum epidermide livescente maculari dein colliculosa lacero-fissa grumulos ovato-subrotundos hemisphaericos immersos polysporos iisque effoetis scrobiculos superficiales nudos praestantibus.

Nordhausen, d. 15. Febr. 1842.

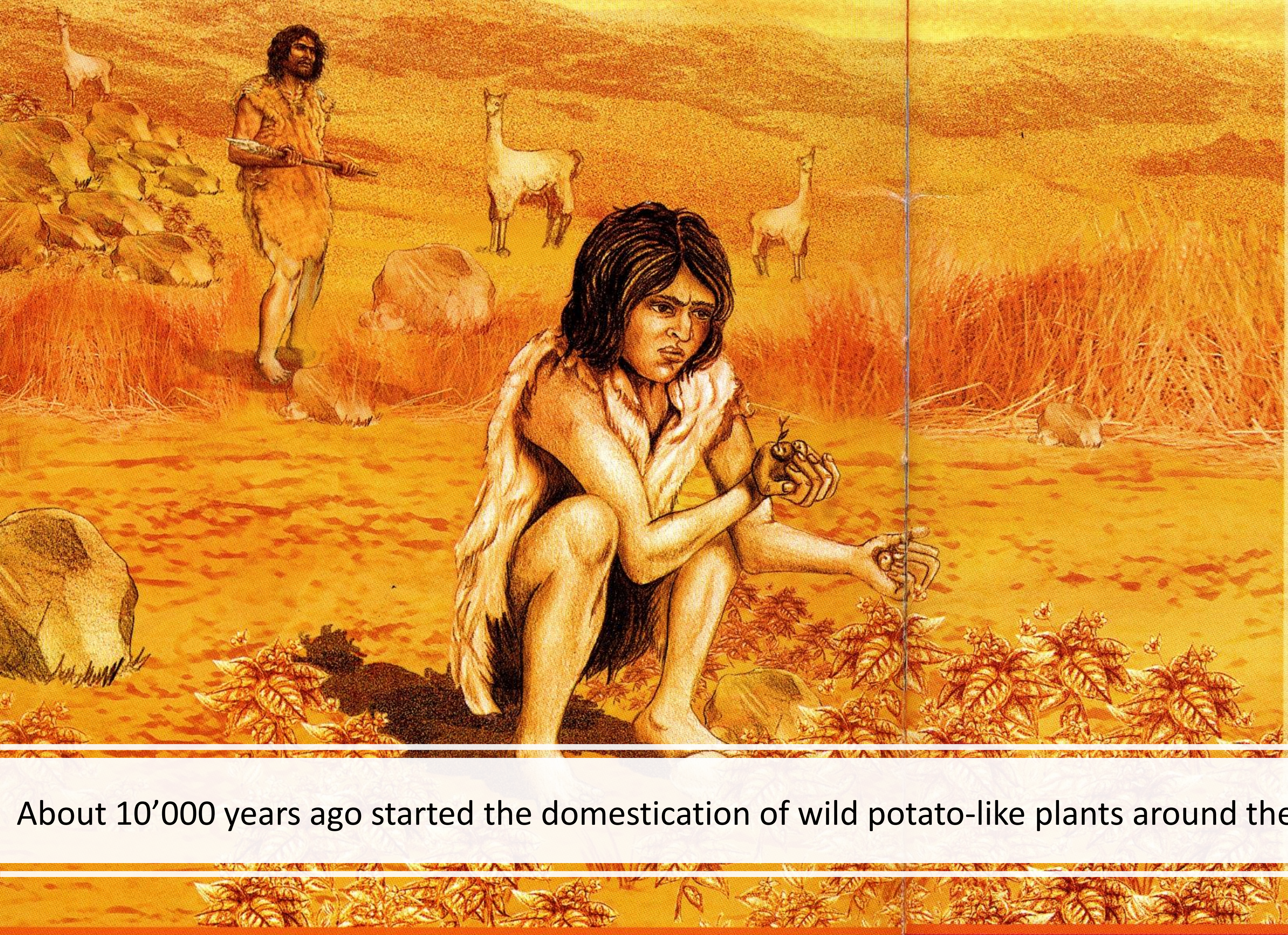
Spongospora subterranea has a long history in agriculture

De Lagerheim G., 1891. Remarks on the fungus of a potato scab (*Spongospora solani* Brunch.)

question. If my supposition be correct, the fungus should be called *Spongospora subterranea* (Wallr.).

MICROBIOLOGICAL LABORATORY AT QUITO, *June 24, 1891.*

It took about 50 years until the pathogen became its actual name '*Spongospora subterranea*' suggested by De Lagerheim.



The domestication of potatoes (*Solanum* spp.) probably started at least 10 000 years ago around Lake Titicaca (in modern-day Peru and Bolivia), when the first inhabitants of this region began selecting edible forms of wild potato species. The wild species eventually crossed with each other and produced increasingly better varieties. The modern potato (*Solanum tuberosum*) was apparently domesticated about 7000 years ago from wild potato species of the *Solanum brevicaule* complex. However, the emergence of agricultural communities, in this and other regions of South America, only occurred some 3800 years ago at the beginning of the Formative Period

About 10’000 years ago started the domestication of wild potato-like plants around the Lake Titicaca (Peru/Bolivia)

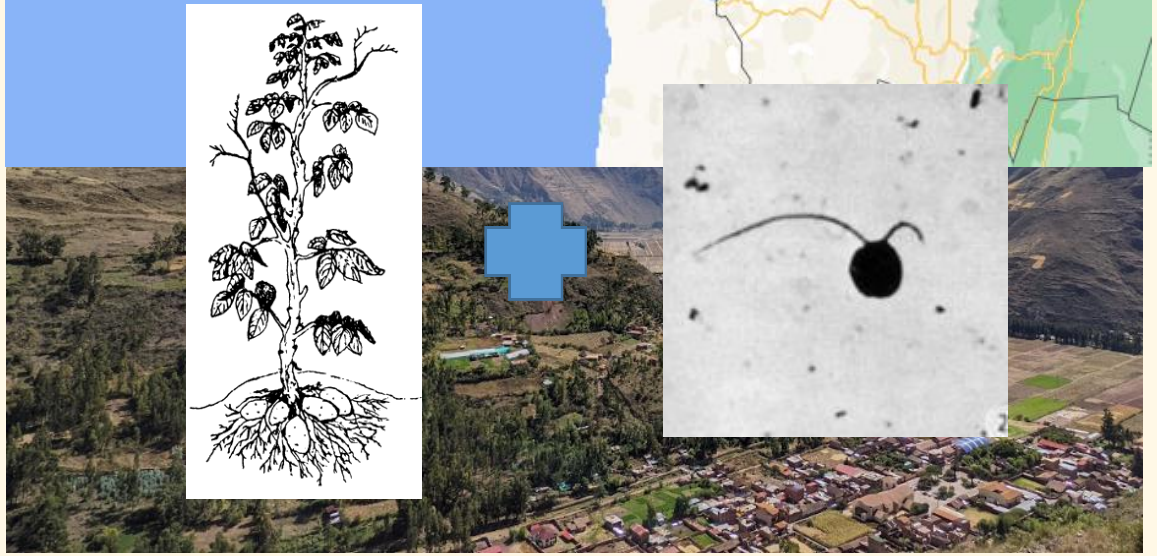
The Odyssey of the Potato. Year of the potato 2008, CIP

Cuzco and Ollantaytambo, Peru. Some of the infected tubers were obtained direct from the fields of the Indians near the upper limit of potato cultivation in the Panticalla Pass, between the Urubamba and Lucumayo valleys, at an altitude of over 12,000 feet. Mr. Cook states that potatoes are never imported in these localities, only the original native varieties being grown. Hence introduction of the disease from Europe or any other foreign locality into this region of primitive potato-growing seems most improbable. Both host and parasite are apparently indigenous.

Lyman G.R. and J.T. Rogers, 1915. The native habitat of *Spongospora subterranea*. Science, December.

The real world by Trafalgar, https://www.trafalgar.com/real-word/peruvian-potatoes/

Google maps, 2023



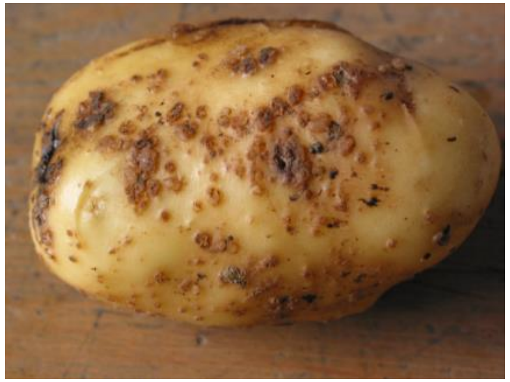
I. Hopkin, Google maps, 2022

Is it possible that the pathogen, which may have been originally an aquatic organism, fused with an ancient potato-like plant in the region of the lake Titicaca?

OK, a bold hypothesis. But let me make a short detour on another road of speculation.

Commercial peat substrate contaminated with *Spongospora*: What is behind this phenomen?

Reports of mini tuber infection with powdery scab after multiplication (trays, pots, floor beds)



1998: Basic seed multiplier (Switzerland)
2000: Breeder (France)
2003: Breeder (Germany)
2004: Basic seed multiplier (Switzerland)
2004: Breeder (Germany)
2005: Basic seed multiplier (Switzerland)
2005: Substrate producer (UK)
2006: Breeder (Germany)
2008: Breeder (Norway)
2012: Breeder (Germany)
2012: Breeder (USA)
2013: Breeder (Germany)
2015: Basic seed multiplier (Switzerland)
2015: State station (Vermicullit/Belgium)
2018: Breeder (Netherland)
2019: Diag. Clinic Colorado (USA)
2020: Breeder (Chile)
2023: Breeder (USA)

Different
- **companies**
- **organisations**
- **countries**
- **years!**

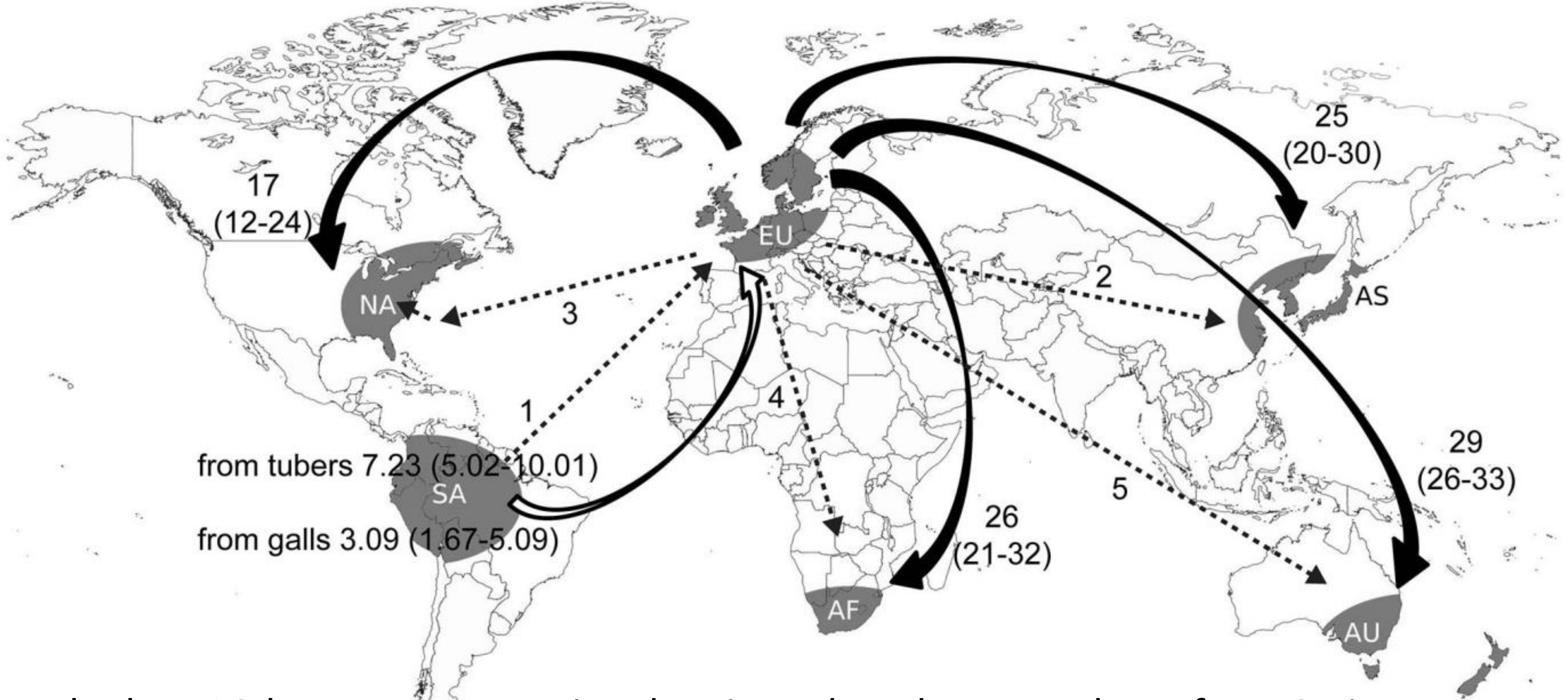
Göldenitzer Moor

- Peat has a swampy history where water and plants have coexisted.
- Is there any relationship to the history of *Spongospora* and potato?
- In the last decade before my final retirement, I focused my research on this phenomen to find the cause and thus help the breeders. As you can imagine it`s a lot of money you loose when you have to dump a complete production
- I'm afraid but although the fact that we, a breeders lab and I, independently found Spongospora-DNA in fresh sampled peat probes – here in this moore in Germany - I couldn't finally manage to prove that peat can originally be contaminated with *Spongospora*, also because of lack of time and money.

End of detour, back to history

First records of potato in South-America were made by members of Spanish expeditions, starting 1537 in Colombia

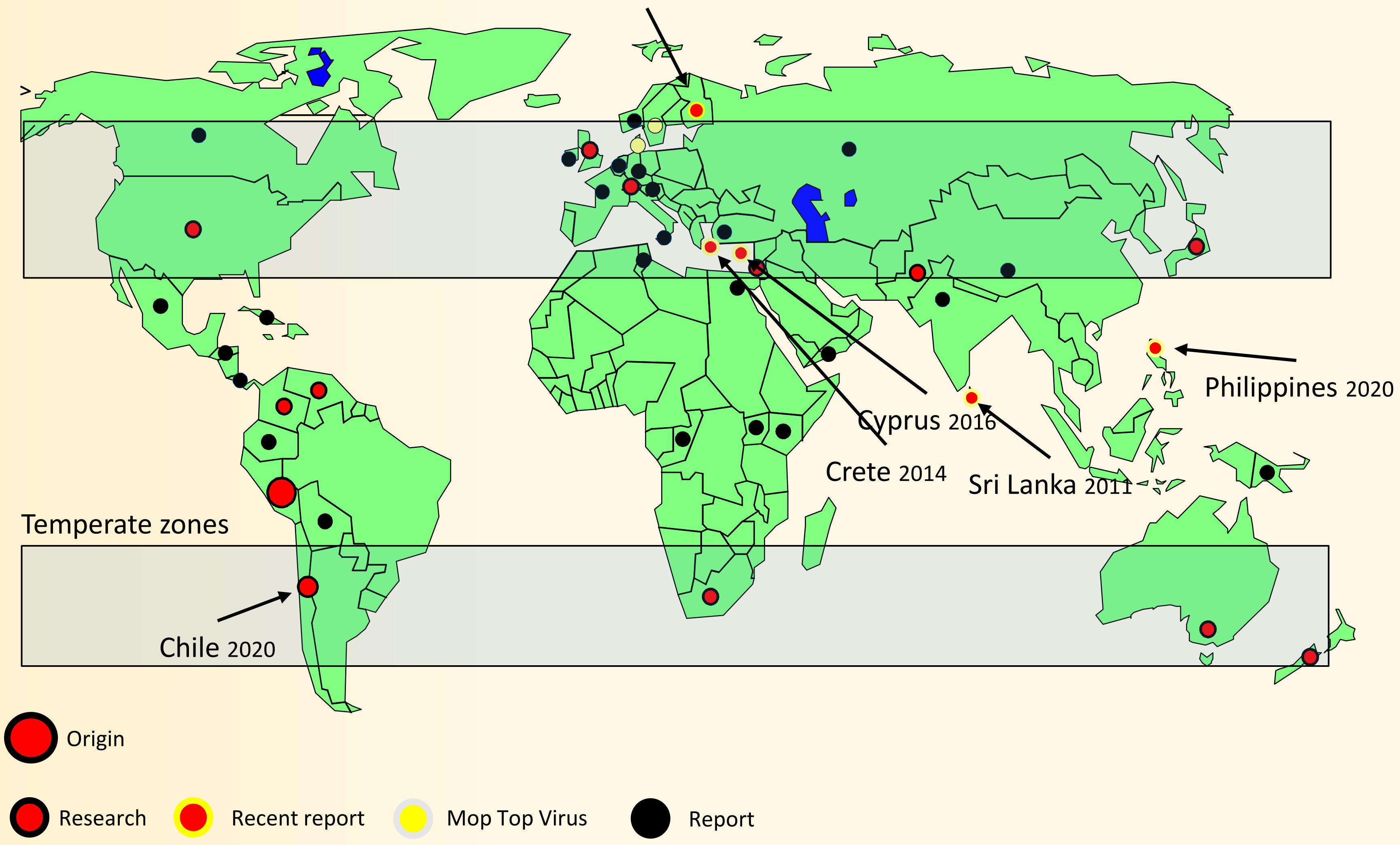
The Odyssey of the Potato. Year of the potato 2008, CIP



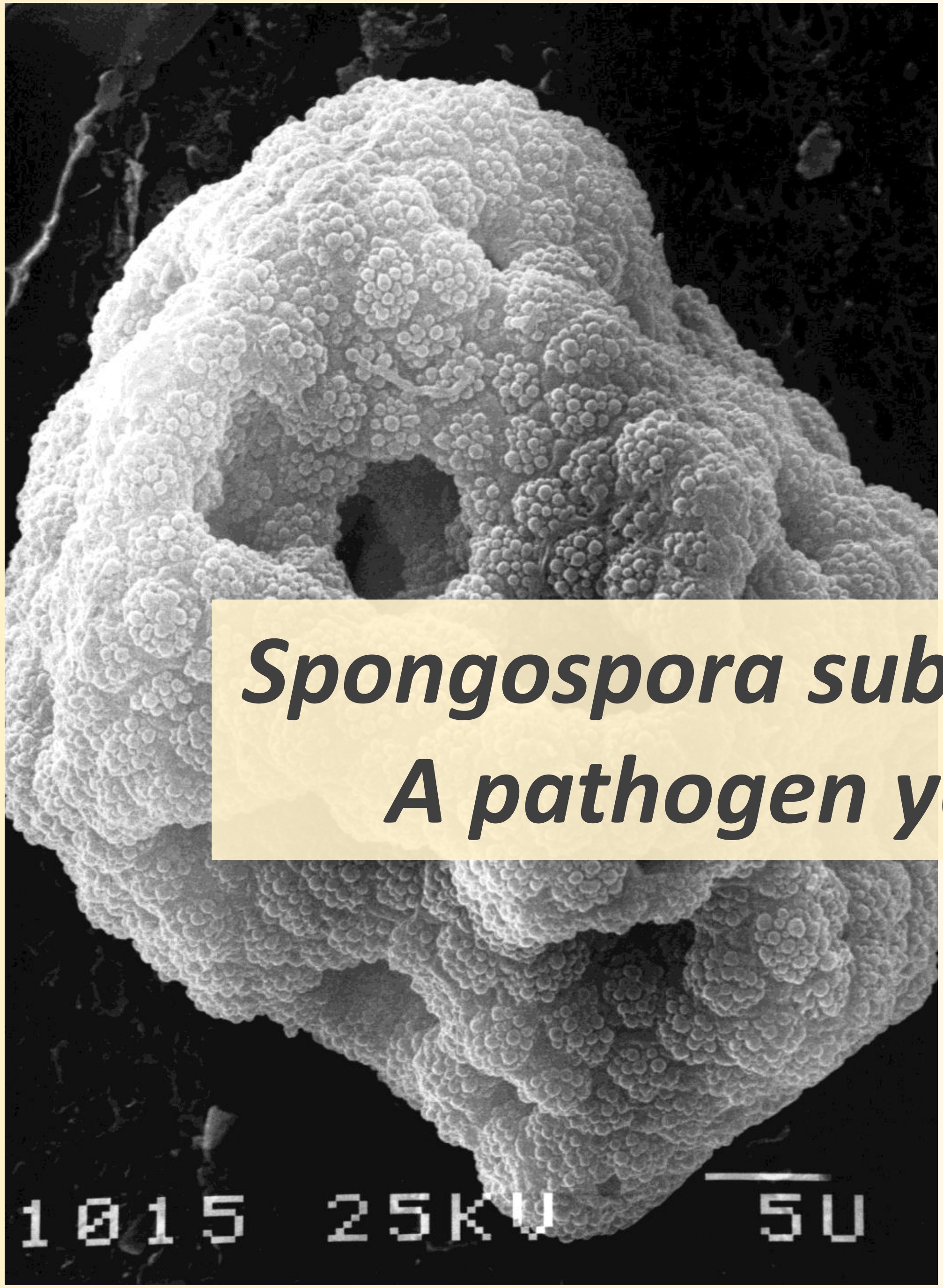
In the late 16th century, conquistadors introduced potato plants from SA into Europe which were later spread to other places by people movement (often Monks).

Gau RD, U. Merz, R.E. Falloon, P.C. Brunner, 2013. Global Genetics and Invasion History of the Potato Powdery Scab Pathogen, *Spongospora subterranea* f.sp. *subterranea*.
PLoS ONE 8(6): e67944. doi:10.1371/journal.pone.0067944

Spongospora worldwide



Today problems with *Spongospora* were widespread and occur mostly in the temperate zones or at higher altitudes (f.i. in the Andes). The most recent reports came from Sri Lanka, Crete, Cyprus, Finland, The Philipines and finally Chile.



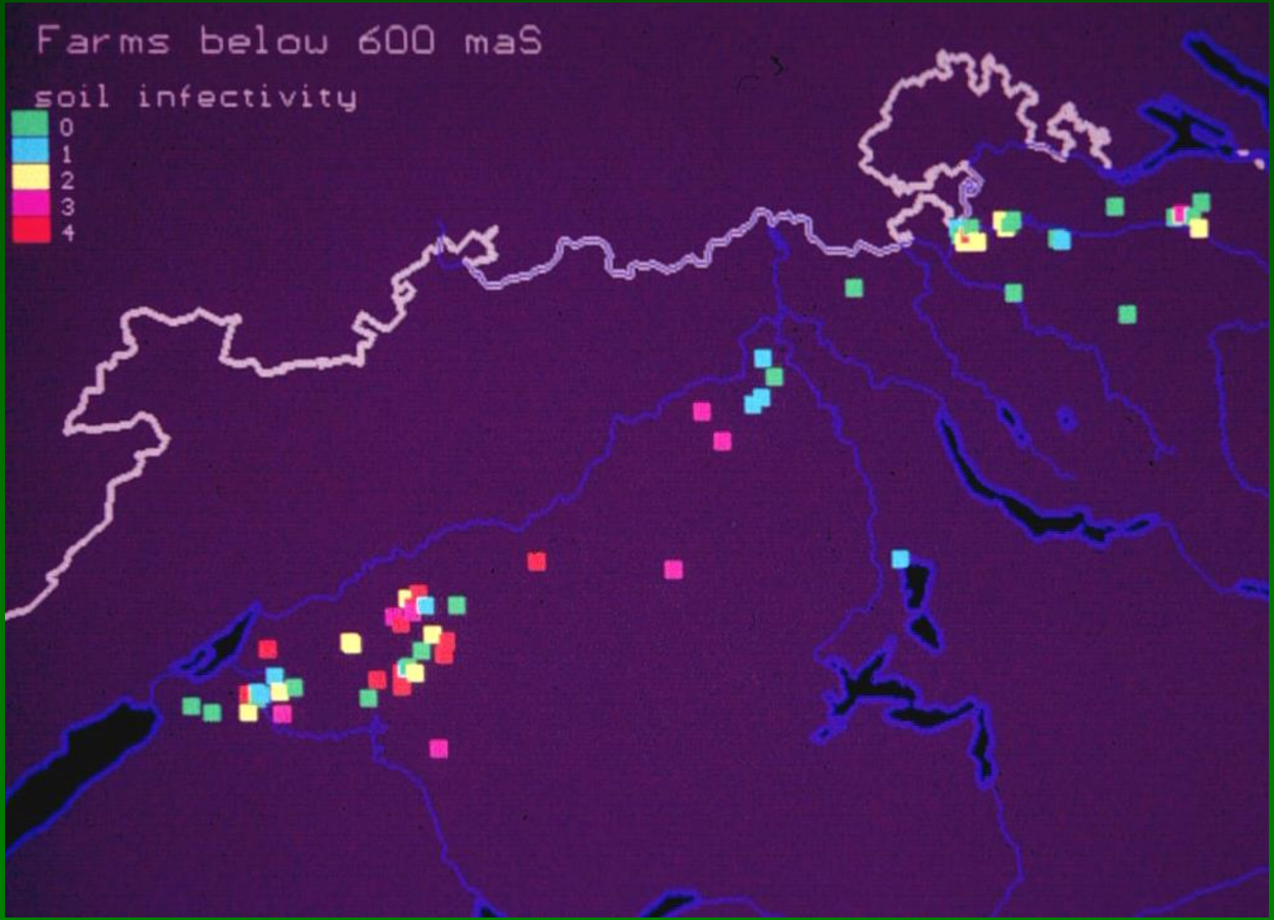
Spongospora subterranea f.sp. *subterranea*: *A pathogen you should never ignore!*

- **1977**: Internship on a farm with seed potato production at 840 m aSl

- Farmer had often problems with powdery scab
- The disease was more present in the hilly regions but began to spread to the lowlands
- **1984**: An application for research money for a PhD project, sent to the Swiss Potato Association
- Their answer: "Our farmers know how to deal with this minor disease"
- **1991**: Lowland farmers reported powdery scab problems with cv Agria and claimed that they never had problems before
- **1992**: Survey of soils on farms cropping cv Agria

Presence of *S. subterranea* in 1992

Contamination level of 78 soils at altitudes < 600 maSl



21 healthy
14 little
15 little-medium
12 medium
16 high

U. Merz, 1999

Powdery Scab

Steadily increasing in incidence, severity and distribution over past decade in SA

- Underestimated and misdiagnosed
- Stigma related to disease
- Long term survival of resting spores in soil
- Intensification of potato production – limit of virgin soil available
- Use of susceptible cultivars
- Irrigation of the crop

J. Van der Waals, SA; 2nd Int. Sss Workshop, Neuchatel 2019

POWDERY SCAB PROJECT UPDATE POTATO R&D FORUM 2022

potatoes australia, summer 22/23 issue

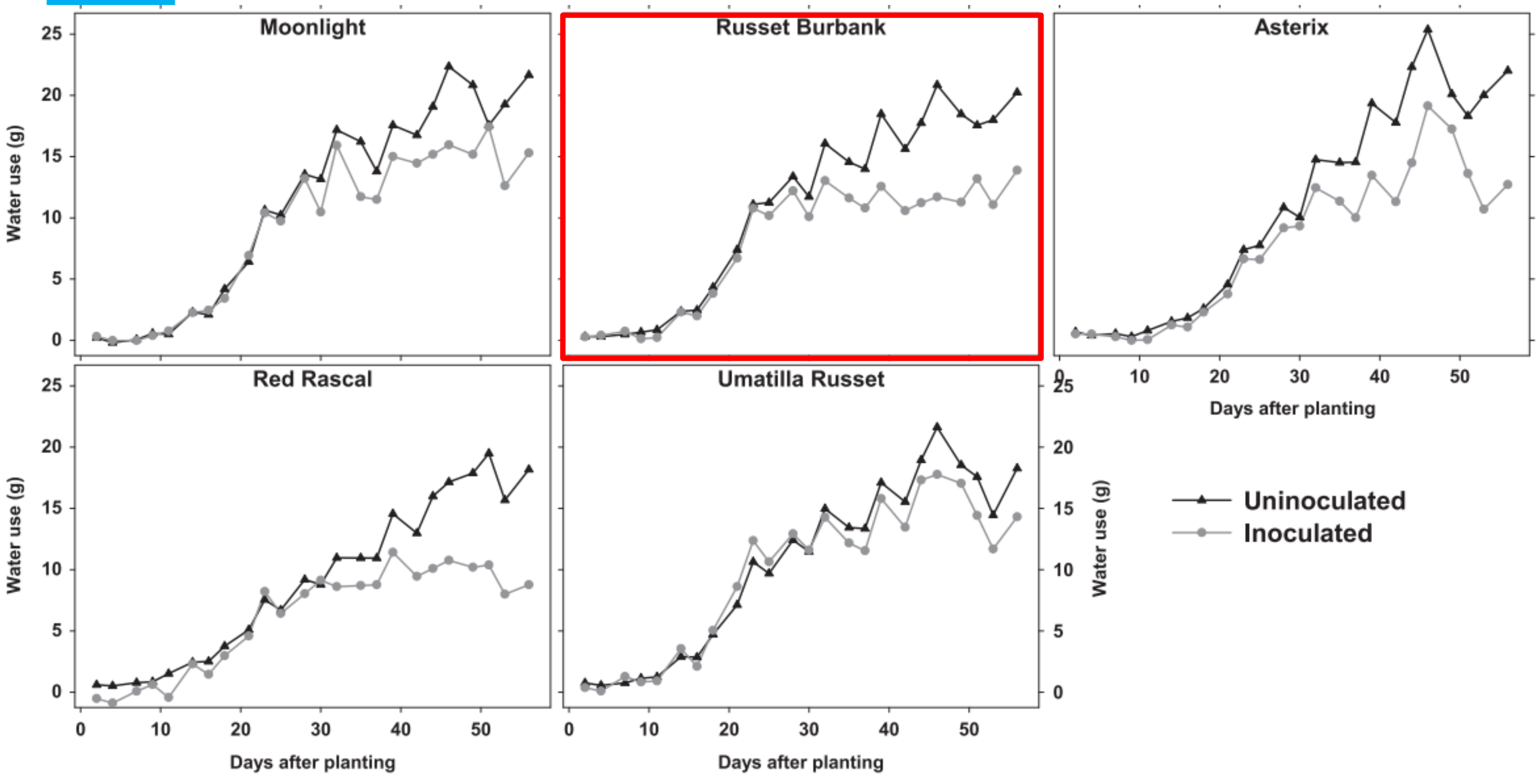
However, it is the effects on the roots which have the greatest influence on yield. Symptoms on root infection are not always visible, with the result powdery scab can be an under-estimated disease.

Statement by Calum Wilson, TIA, Australia; project leader

Plant Pathology (2015) Doi: 10.1111/ppa.12419

BSPP

Root infection of potato by *Spongospora subterranea*: knowledge review and evidence for decreased plant productivity



Resistance to Root Galling Caused by the Powdery Scab Pathogen *Spongospora subterranea* in Potato

2008

Nadav Nitzan, USDA-ARS, Prosser, WA 99350; **Tom F. Cummings** and **Dennis A. Johnson,** Washington State University, Pullman, WA 99164; **Jeff S. Miller,** Miller Research, LCC., Rupert, ID 83350; **Dallas L. Batchelor,** Weather Or Not, Pasco, WA 99301; **Chris Olsen,** L.J. Olsen, Inc., Othello, WA 99344; **Richard A. Quick** and **Charles R. Brown,** USDA-ARS, Prosser, WA 99350

ABSTRACT

Nitzan, N., Cummings, T. F., Johnson, D. A., Miller, J. S., Batchelor, D. L., Olsen, C., Quick, R. A., and Brown, C. R. 2008. Resistance to root galling caused by the powdery scab pathogen *Spongospora subterranea* in potato. Plant Dis. 92:1643-1649.

Potato (*Solanum tuberosum*) selections (clones and commercial cultivars) were examined for

and their growth during the season could be retarded, affecting yield weight (6,11,25). Tubers infected with *S. subterranea* were reported to be more susceptible to potato pathogens such as *Phytophthora infestans*, *P. erythroseptica*, *Fusarium* spp., and *Colle-totrichum atramentarium* (*C. coccodes*)

"The potato industry of Washington State is concerned with damage to roots caused by powdery scab and its potential to reduce yield weight in tonnage and affect tuber size and quality."

Root infection

Root cell disfunction causes **reduced yield**

Infection is often **overlooked** because hardly visible at harvest time

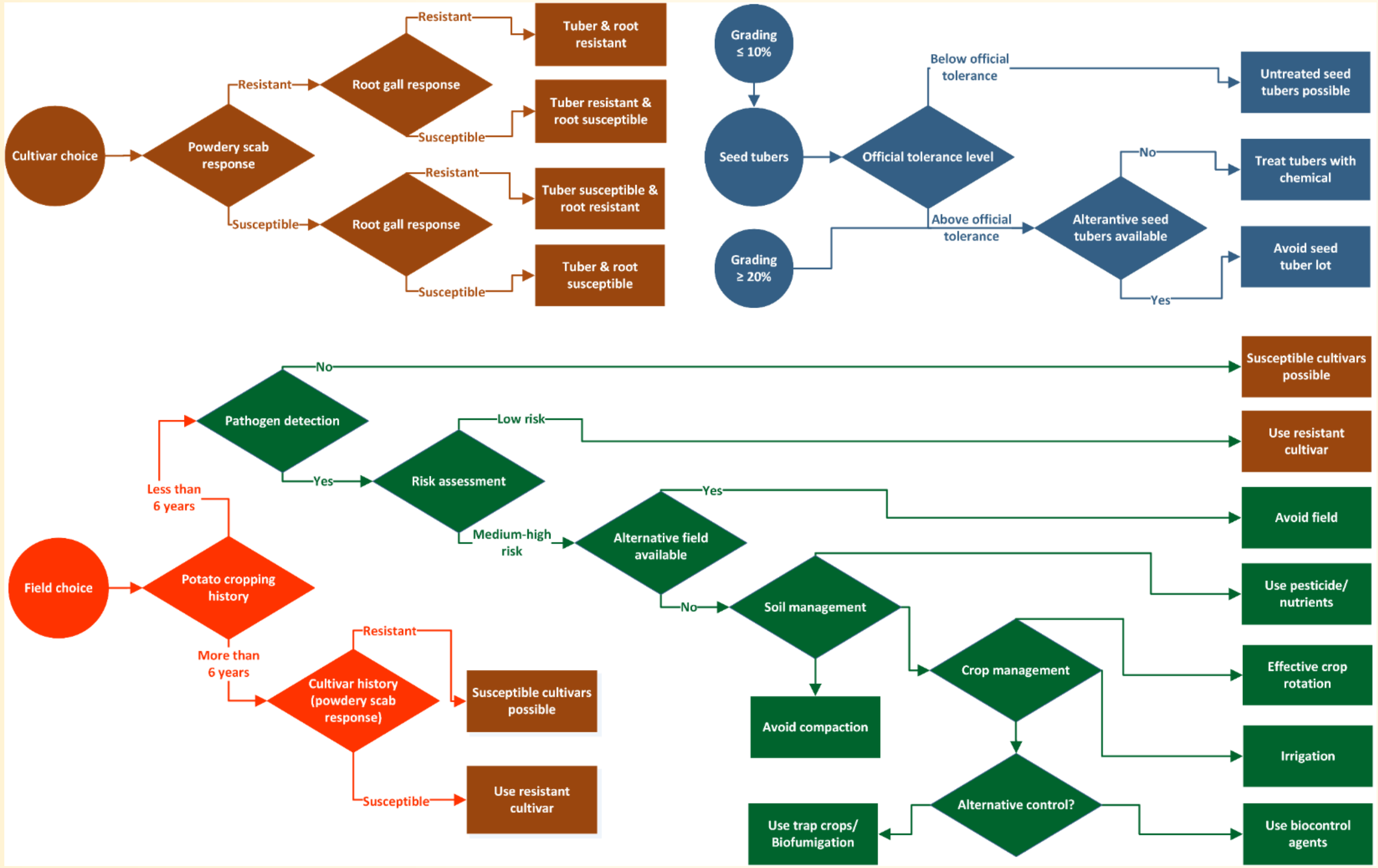
Especially risky are cultivars with little susceptibility to powdery scab but prone to root infection

The production of a huge number of sporosori **increases soil inoculum** and a field, once contaminated, stays infectious for many years

Current knowledge of *S. subterranea* and epidemiology of the diseases it causes allows formulation of grower guidelines based on integrated disease management options

Host resistance

Field history



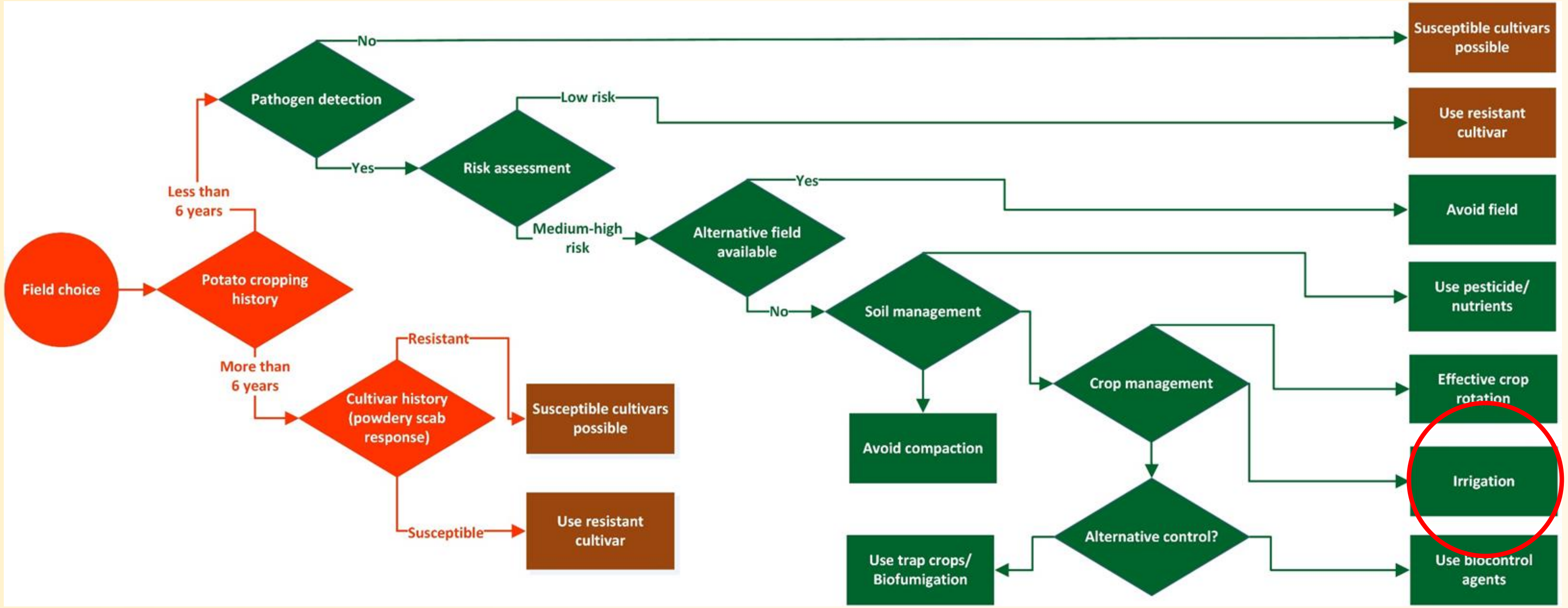
Seed tuber quality

Merz U. and R. Falloon eds. (2017). Proceedings of the 3rd International Powdery scab Workshop, Einsiedeln, Switzerland, July 18-21, 2016. Potato Research 60(2), 195-215.

Necessary tools for an integrated disease management

- Potato cultivars with both root and tuber resistance/tolerance
- Efficient grading concepts for seed with no/low infection rate
- Accurate and cost effective soil tests
- Reliable information on disease risks of soil contamination levels
- Appropriate irrigation management
- Efficient biocontrol agents/biofumigation cultivars
- Efficient fungicides with low environmental impact

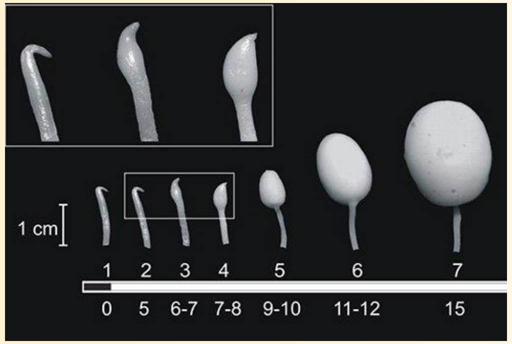
Irrigation management



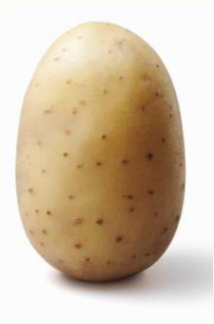
Merz U. and R. Falloon eds. (2017). Proceedings of the 3rd International Powedry scab Workshop, Einsiedeln, Switzerland, July 18-21, 2016. Potato Research 60(2), 195-215.

Control of *S. subterranea* (Recommendation)

Tuber Initiation



until tubers 25-30mm



about 6 weeks after planting

for 4-5 weeks

Why?

The emerged zoospores need free soil water to find susceptible host tissue!

Water dilemma


Joseph LaForest, University of Georgia, Bugwood.org

On one hand

The concerned growth period is important and reduced water availability will reduce yield

Irrigation will be an important yield factor in the future, facing global warming

On the other hand

Irrigation favors diseases caused by *Spongospora*

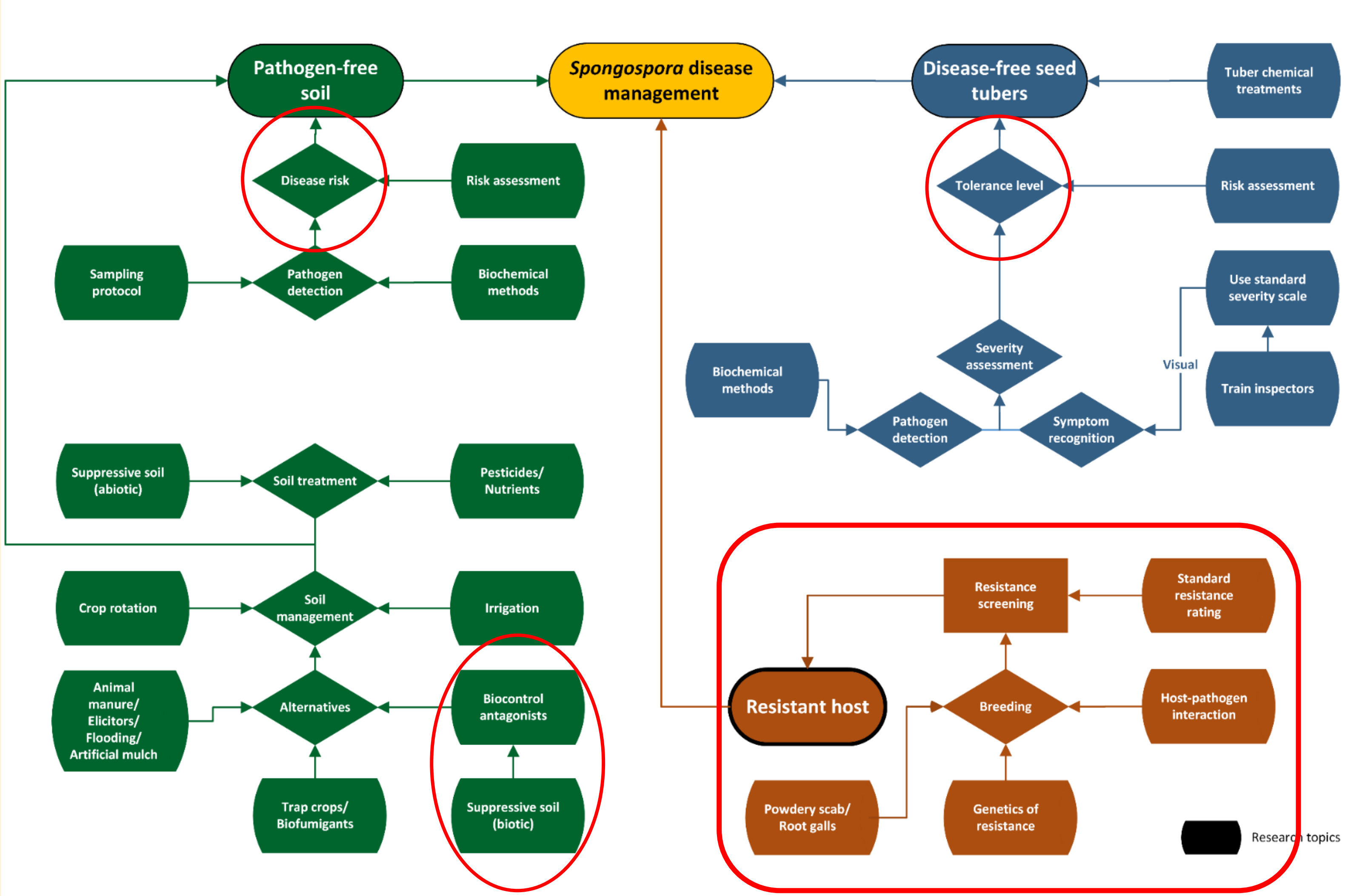
Too much soil water content enhances proliferation of lenticells – entrance ports for the pathogen

Reduces availability of oxygen – reduced barrier capability to stop pathogen after infection

Colorado state, USA

Intensification of irrigation is raising the risk of a ‘comeback’ of powdery scab in places where producers became careless

We also outlined key areas of research where knowledge is lacking on the diseases *S. subterranea* causes, and strategies for their practical management



Merz U. and R.Falloon eds. (2017). Proceedings of the 3rd International Powdery Scab Workshop: Einsiedeln, Switzerland, July 18–21, 2016. Potato Research 60(2), 195-215

Host resistance

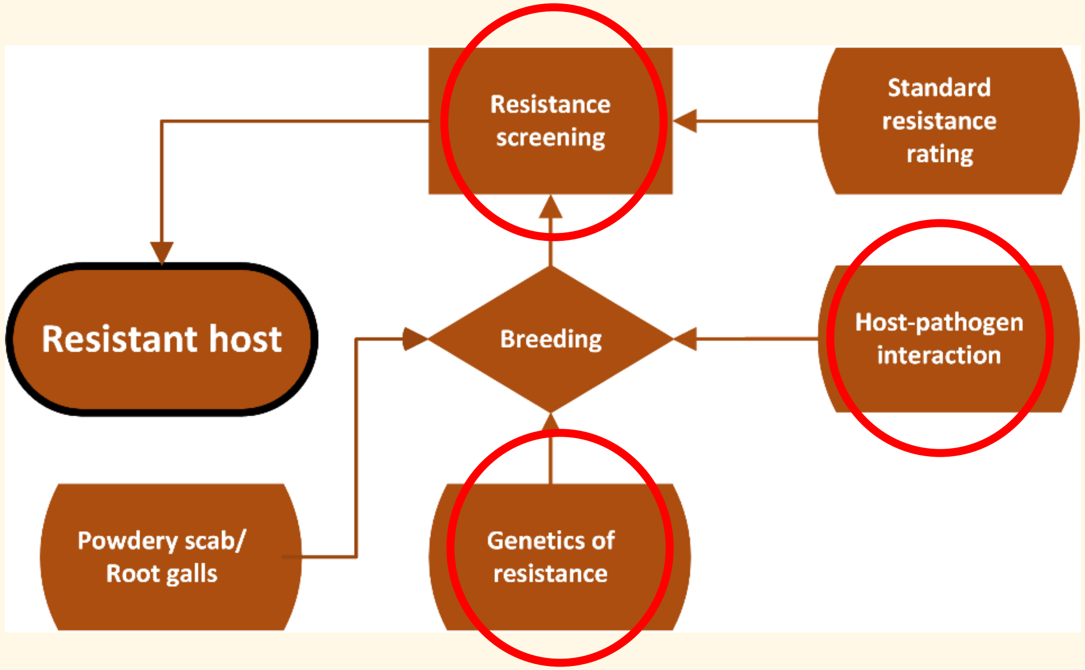
Breeding means to understand the mechanism of host resistance:

<u>Need for more knowledge of</u>

- host/pathogen interaction

- genetics of resistances

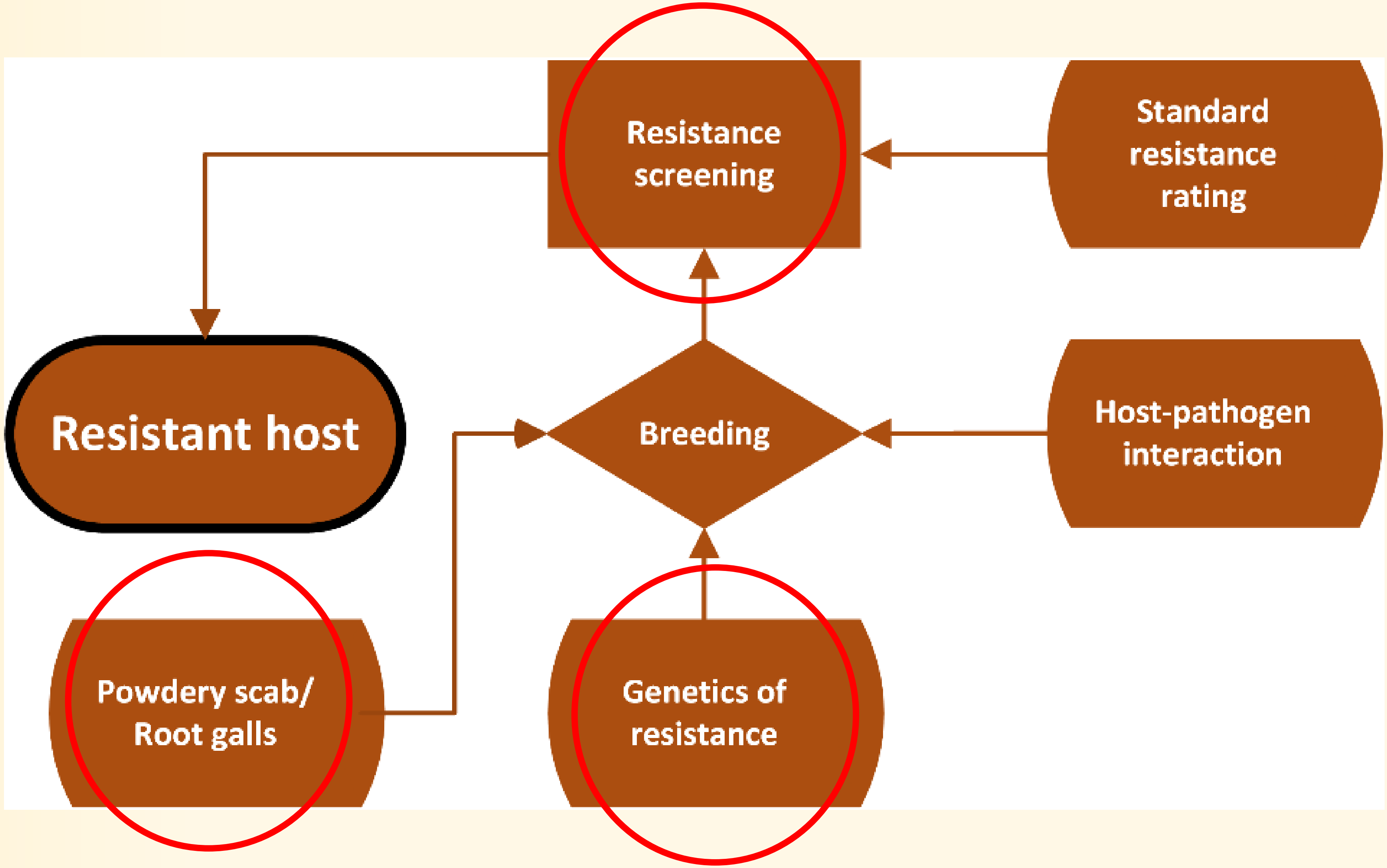
- methods of resistance screening



The challenge

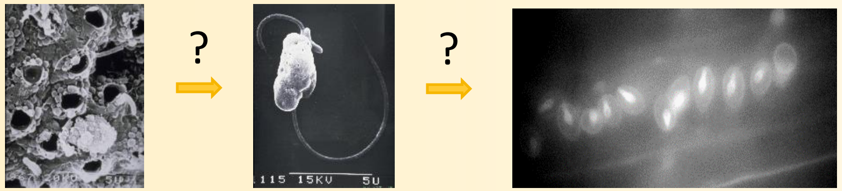
Host resistance:

- **Two diseases (or three?)**
- **Two resistance levels**
- **Two genetics of resistance**

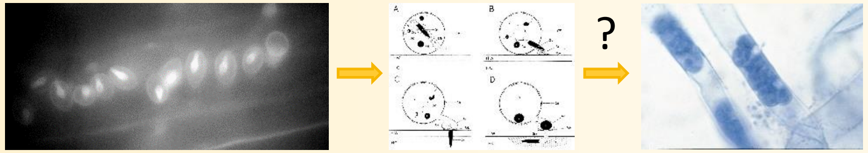


Host/pathogen interaction

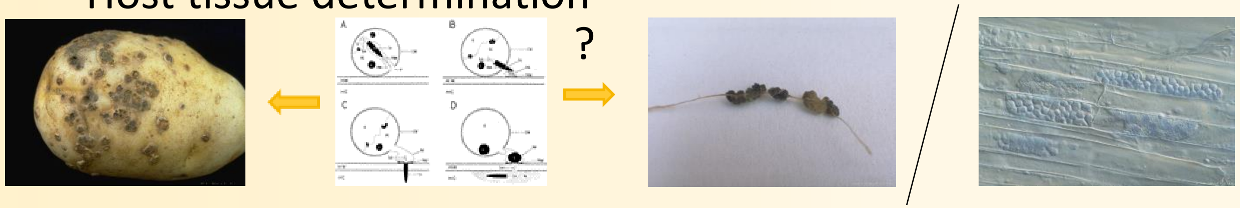
Zoospore release, attraction and attachment



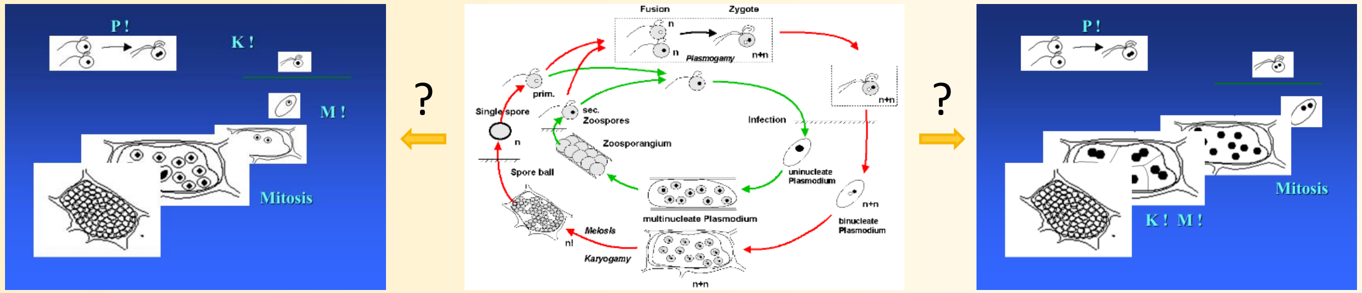
Penetration and plasmodial development



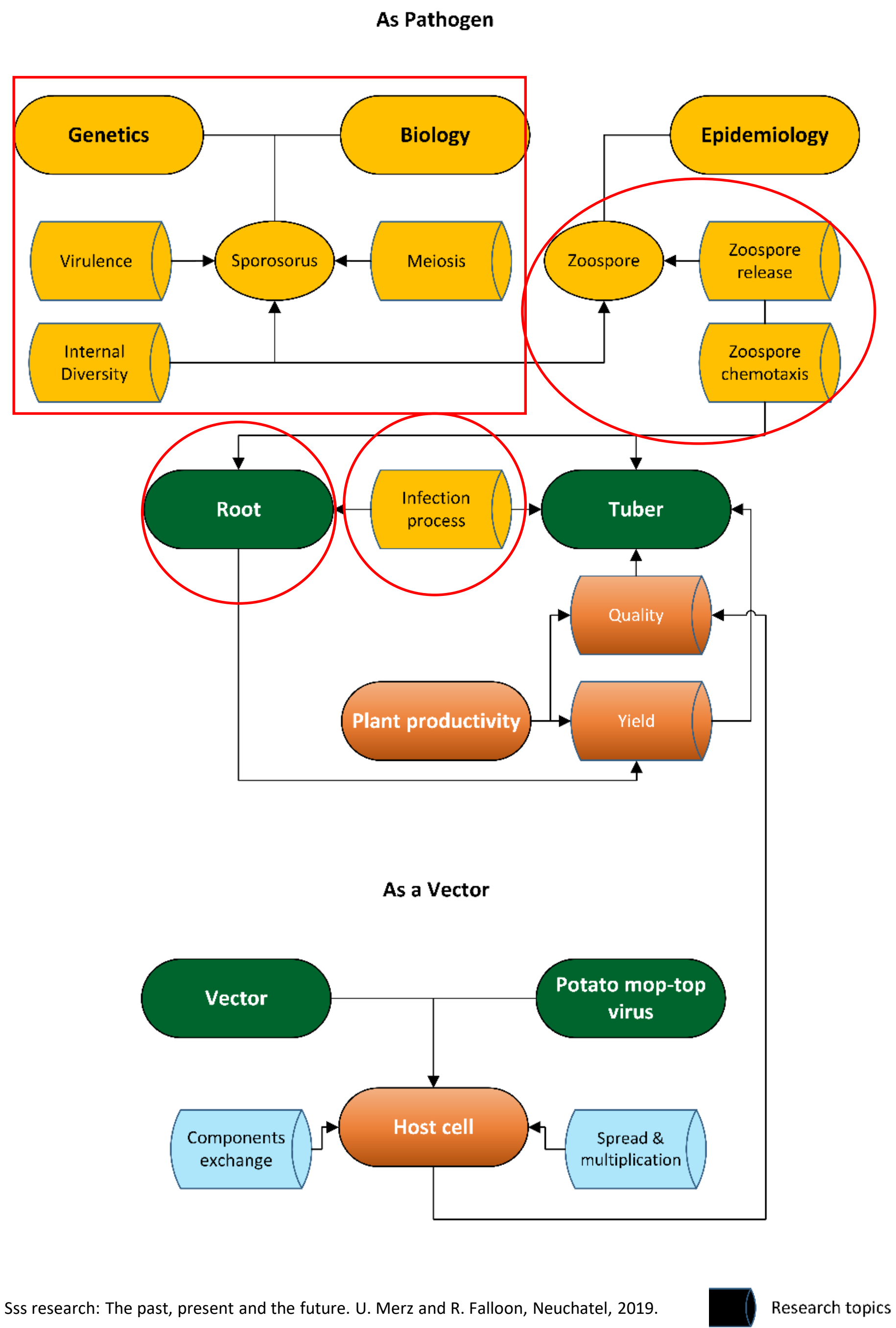
Host tissue determination



Recombination, population genetics and virulence



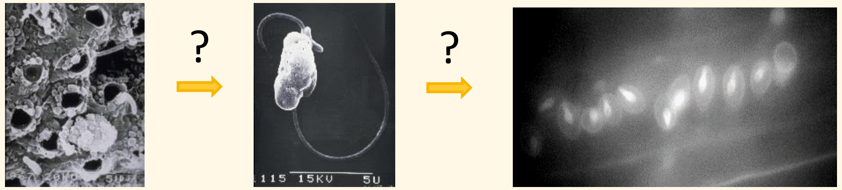
Spongospora subterranea research



Sss research: The past, present and the future. U. Merz and R. Falloon, Neuchatel, 2019.

Host/pathogen interaction

Zoospore release and attraction



Zoospore release

- sporosori contain both exogenous (stimuliresponsive) and constitutively dormant resting spores

- root exudates stimulate release but no difference between host and non-host

- release of germination-stimulant compounds independent of host susceptibility

Balendres, M.A.,Tegg, R.S. and Wilson, C.R., 2017. Resting Spore Dormancy and Infectivity Characteristics of the Potato Powdery Scab Pathogen Spongospora subterranea. Journal of Phytopathology 165 (5), 323-330.

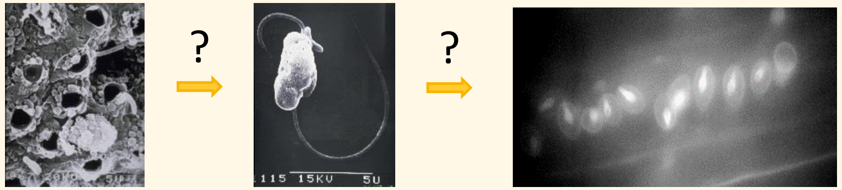
Balendres M.A. Nichols D.S., Tegg R.S. et al., 2016. Metabolomes of Potato Root Exudates: Compounds That Stimulate Resting Spore Germination of the Soil-Borne Pathogen Spongospora subterranea. Journal of Agriculture and Food Chemistry 64 (40), 7466-7474.

Balendres M.A. Nichols D.S., Tegg R.S. et al., 2017. Potato Root Exudation and Release of Spongospora subterranea Resting Spore Germination Stimulants are Affected by Plant and Environmental Conditions. Journal of Phytopathology 165 (1), 64-72.

Zoospore release shows neither a host/non-host effect nor is it connected to host susceptibility

Host/pathogen interaction

Zoospore release and attraction



Root attachment

- cell wall pectin content has a potential role in regulating zoospore root attachment

- latex proteins and glucan endo-1,3-beta-glucosidase involved in zoospore binding to potato roots

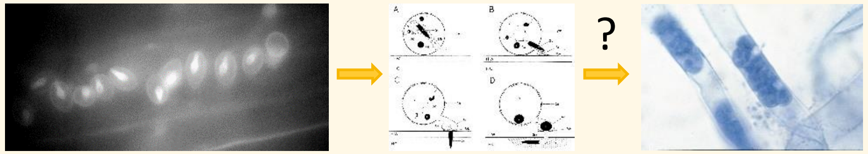
Xian Y., R. Wilson, S. Balotf et al., 2022. Comparative proteomic analysis of potato roots from resistant and susceptible cultivars to Spongospora subterranea zoospore root attachment In Vitro. Molecules 2022, 27, 6024.
https://doi.org/ 10.3390/molecules27186024

Xian Y., R. Wilson, A. Eyles et al., 2023. Enzymatic investigation of Spongospora subterranea zoospore attachment to roots of potato cultivars resistant or susceptible to Powdery Scab disease. Proteoms 11, 7,
DOI: http://doi.org/10.3390/proteomes11010007

Specific cell wall chemicals stimulate zoospore attachment which may increase the risk of root infection

Host/pathogen interaction

Penetration and plasmodial development



Host cell penetration

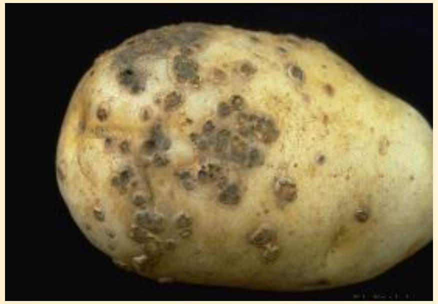
We know that the host cell penetration is a mechanical procedure – a bullet opens a whole in the cell wall so that the protoplast can enter and form the uninucleate plasmodium, the first post-infection stage

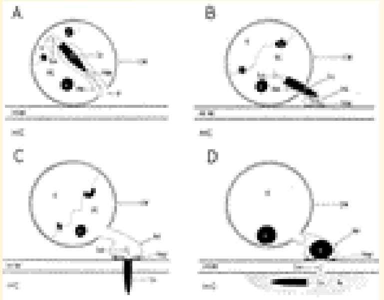
Is the thickness of the cell wall e.g. involved in resistance?

What about further development of the plasmodium?

Host/pathogen interaction

Post infection development of plasmodium: Host tissue determination





?

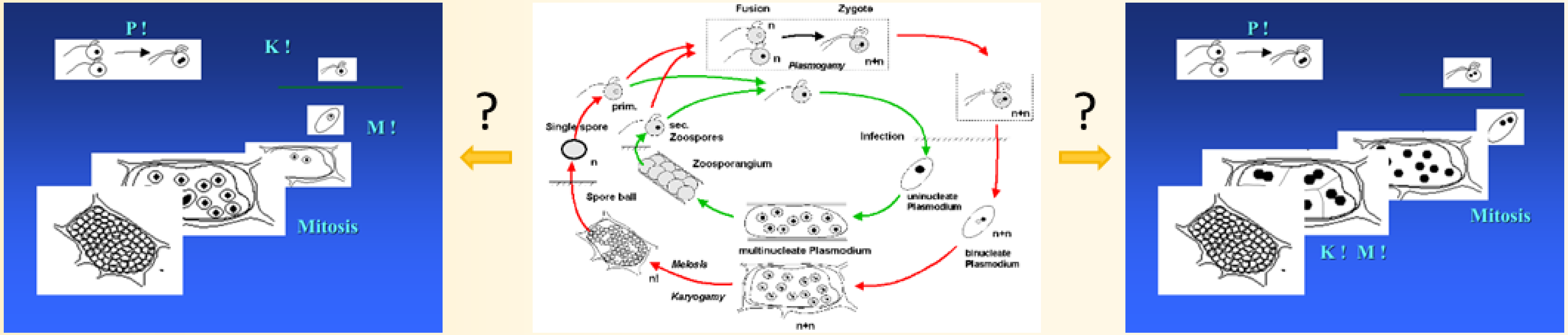
Plasmodiophora brassicae

Primary zoospores first infect the root hairs, producing motile zoospores (sec. zoospores) that invade the cortical tissue.

Secondary plasmodia form within the root cortex and, by triggering the expression of genes involved in the production of auxins, cytokinins and other plant growth regulators, divert a substantial proportion of plant resources into hypertrophic growth of the root tissues, resulting in the formation of galls

Pathogen genetics

Recombination, population genetics and virulence



- Another mistery is the genetic composition of a sporosorus: Are all single spores a clone or do they have different genetics?
- A similar question applies for alle the sporosori in a gall or lesion
- The crucial question here is: When does karyogamy and meiosis happen in the life cycle of *Spongospora?*

Host resistance: Potential markers for breeding I

- Increase selection pressure/ careful selection of parents

Paget, M.F., Alspach, P.A., Genet, R.A., et al., 2014. Genetic variance models for the evaluation of resistance to powdery scab (Spongospora subterranea f. sp subterranea) from long-term potato breeding trials. EUPHYTICA 197 (3), 369-385.

- The physiological levels of Lipoxygenase protein can be considered as a useful marker for powdery scab resistance in potato breeding programs.

Perla, V., Jayanty, S.; Holm, D.; et al. 2014. Relationship Between Tuber Storage Proteins and Tuber Powdery Scab Resistance in Potato. American Journal of Potato Research 91 (3): 233-245.

- Our results demonstrate that the alkalinization response is an effective marker to study early stages of defense response in potatoes.

Moroz N., K.R. Fritch, M.J. Marcec, D. Tripathi, A. Smertenko and K. Tanaka, 2017. Extracellular Alkalinization as a Defense Response in Potato Cells. Frontiers in Plant Science 8, Art. 3

- The results of this preliminary study suggest that the tolerant potato cultivar employs quantitative resistance and salicylic acid pathway hormonal responses against tuber infection by *Sss* – tool for marker-assisted breeding

Lekota M., N. Muzhinji and J.E. van der Waals, 2019. Identification of differentially expressed genes in tolerant and susceptible potato cultivars in response to Spongospora subterranea f. sp. subterranea tuber infection. Plant Pathology 68 (6), 1196-1206

- This study illustrated that *Sss* infection of potato roots leads to differential expression of metabolites in tolerant and susceptible potato cultivars.

Lekota M., K.J. Modisane, Z. Apostolides et al., 2020. Metabolomic fingerprinting of potato cultivars differing in susceptibility to Spongospora subterranea f. sp. subterranea root infection. Int. J. of Molecular Sciences 21 (11), doi:10.3390/ijms21113788

Host resistance: Potential markers for breeding II

- This study provides new insight into potato resistance to *Sss* infection and has identified new roles for protein phosphorylation in the regulation of potato immune response.

Balotf S., C.R. Wilson, R.S. Tegg, D.S. Nicols and Wilson, 2022. Large-scale protein and phosphoprotein profiling to explore potato resistance mechanisms to Spongospora subterranea infection. Frontiers in Plant Science,

DOI: 10.3389/fpls.2022.872901

- We provide large-scale multi-omics data of *Sss-potato* interaction and suggest an important role of glutathione metabolism in disease resistance.

Balotf S., R. Wilson, D.S. Nicols, R.S. Tegg, and C.R. Wilson, 2022. Multi-omics reveals mechanisms of resistance to potato root infection by Spongospora subterranea. Scientific Reports 12:10804, https://doi.org/10.1038/s41598-022-14606-y

- Effector Mining: The plant components involved in the HR will be genetically identified and may provide novel R-gene sources for marker-assisted breeding

Leyva-Pérez M. et al., 2022. ScabEomics: Effector-based breeding for resistance to Spongospora subterranea (powderyscab) in potato. Poster at 11th World Potato Congress, May 30-June 2, Dublin Ireland

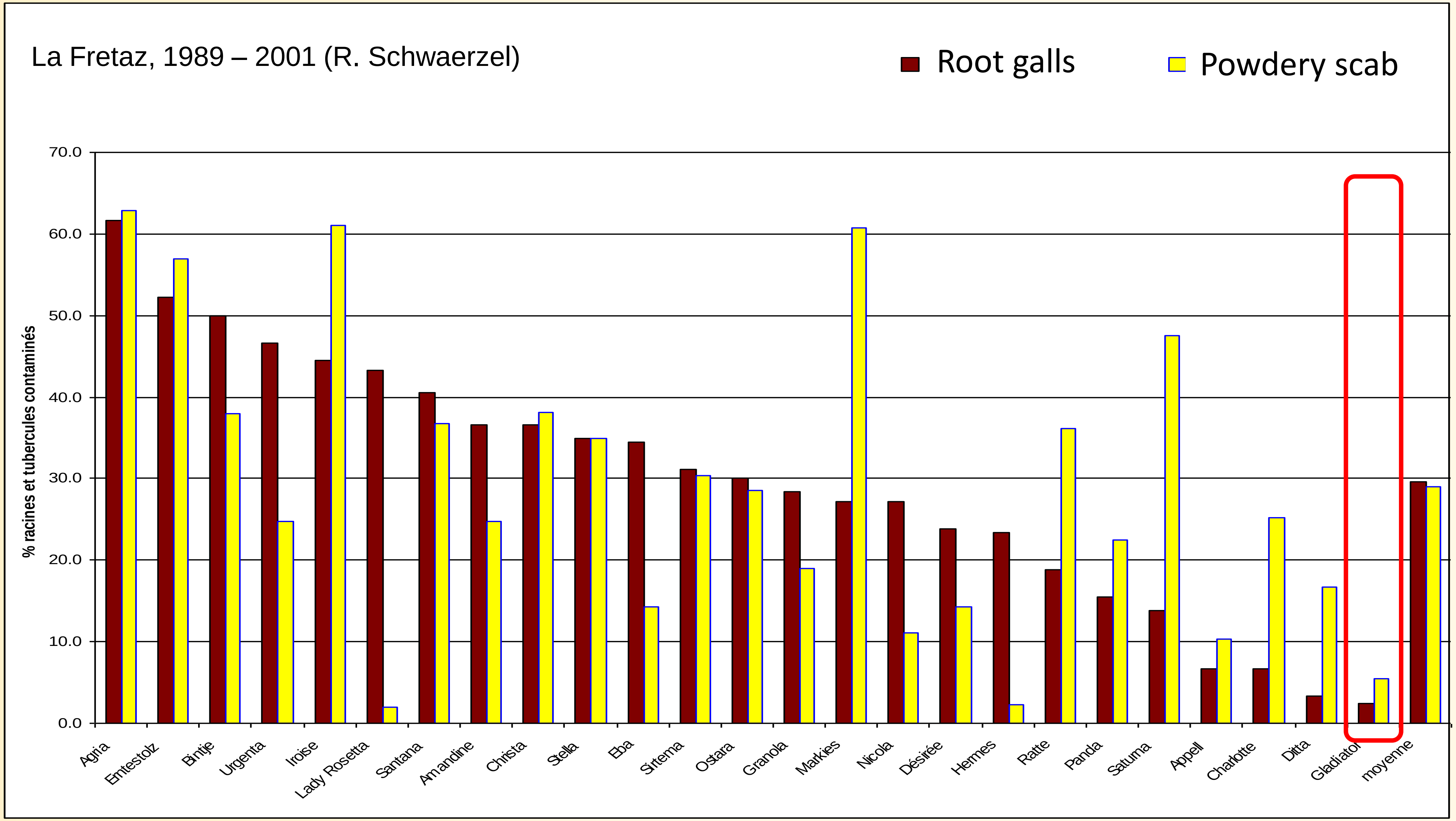
We will here more about this in the presentation of Mariola Leyva-Pérez

Resistance screening

HZPC keeps you growing

Novel bioassay with potao plantlets, sand and NS

Future goal: Resistant/Tolerant cultivars



Gladiator, a cultivar from NZ! Almost immune to root and tuber infection und this under high disease pressure!

To producers

- be always aware of the risk of a disease outbreak caused by *Spongospora*

To researchers, breeders and organisations

- optimize the practical application of the integrated disease management options
- find out more about the host-pathogen relationship and pathogen genetics
- define reliable marker to enable assisted breeding for both powdery scab and root gall resistance
- use informative indoor resistance screening systems to find promising lines
- keep contaminated test fields for outdoor resistance screening
- be more aware of the need to include *Spongospora* resistance too while evaluating new cultivars

First announcement

3rd International *Spongospora* Workshop

6 July, 2024

Satellite meeting of the 22nd Triennial Conference of the European Association for Potato Research, Scandic Fornebu Hotel, Oslo, Norway

Soon online on 'www.spongospora.net/Oslo_2024'