



PPP-final report

PPP projects which are under supervision of the "Topsectoren" must file a final report concerning the total project period. This form is used to report the content of the project. There is a separate form for the financial reporting.

The final report will be published on the TKI / topsector website. Therefore, please ensure that there is no confidential information in the final report.

The PPP-final report must be sent, at the latest, by the 1st of March 2020 to the "TKI's": info@tkitu.nl or info@tki-agrifood.nl. For Wageningen Research, the report has to be sent to the "Topsector secretary" of your respective institute.

General information	
PPP-number	KV 1406-056
Title	An integrated genomics and effectoromics impulse for potato wart resistance management and breeding
Theme	Duurzame Plantaardige Productie
Implementing institute	WUR Plant Breeding
Project leader research (name + e-mail address)	Jack Vossen;jack.vossen@wur.nl
Coordinator (on behalf of private partners)	Stan Oome
Project-website address	n.v.t.
Start date	1-4-2015
Final date	1-12-2019

Approval by the coordinator of the consortium

The final report must be discussed with the coordinator of the consortium. The "TKI's" appreciate additional comments concerning the final report.

Assessment of the report by the coordinator on behalf of the consortium:	<input checked="" type="checkbox"/> Approved <input type="checkbox"/> Not approved
Additional comments concerning the final report:	no

Consortium

Mention any changes in the composition of the project partners:	no
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Summary of the project

Problem definition	Wart disease in potato is caused by the obligate biotrophic fungus <i>Synchytrium endobioticum</i> and is subject to quarantine containment. Unlike other diseases, the deployment of resistant varieties is the only protection strategy. Virulence towards resistance genes in the resistant varieties is the basis of the current pathotype classification system. At the start of the project there was lack of knowledge about resistance from the plant side and (a) virulence from the pathogen side. Also, the available phenotyping systems had limitations as they are time consuming and sometimes produce ambiguous results. This
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	situation urged for an -omics based impulse for wart resistance management and breeding
Project goals	In this project we acquired insights in the way (polygenic) disease resistance against <i>Synchytrium endobioticum</i> pathotypes is build up. This knowledge was used to develop simplified, unambiguous functional and molecular tools for pathogen race typing, essential for resistance based quarantine management. Furthermore, molecular markers for wart disease resistance genes in breeding programs were developed and were deployed to identify complementary wart resistance sources in breeding and germplasm material. This combined public private research effort will create a major breakthrough in potato wart disease resistance management and breeding.

Results	
Planned results in the original project plan	<ul style="list-style-type: none"> - <i>Synchytrium endobioticum</i> genome sequence - Identification of the first <i>S. endobioticum</i> Avr gene - Molecular markers for resistance management - Molecular markers for resistance breeding and germplasm analysis - Genome sequences of resistant potato varieties
Achieved results	<p>All of the above results have been achieved.</p> <p>Additional results:</p> <ul style="list-style-type: none"> - The genomes of three additional Chytrid species and their mitochondrial genomes were sequenced. - Novel phenotyping tools for pathogen isolates and resistant plants (Avr response and shoot inoculation method) - Novel genotyping tool (CoSSA), that is applicable for genetic mapping for monogenic and polygenic traits in tetraploids, map-based cloning, germplasm and pedigree analysis.
Explanation of changes relative to the project plan	We have not deviated from the project plan

What was the added value created by the project for:	
Participating "Knowledge Institutes" (scientific, new technologies, collaboration)	Besides the achievements of PhD theses and publications (listed below), a leading position was acquired in the field of Chytrid genomics, and wart disease resistance research. Collaborations within the Netherlands have been strengthened (NPPO, and the consortium partners). Novel collaborations have been established internationally with labs in Germany, Poland, Ireland and Canada.
Participating private partners (practical application of the results, within which period of time?)	<ul style="list-style-type: none"> - A more comprehensive view of pathotype structure (inter and intra-isolate diversity) was established. - A near complete overview of resistant breeding material was obtained. - The project deliverables listed below have been directly implemented in the research pipelines of the participating companies: <ul style="list-style-type: none"> • Molecular markers for resistance management • Molecular markers for resistance breeding • Phenotyping tools for pathogen isolates and resistant plants • The CoSSA genotyping tool

Society (social, environment, economy)	<p>The insights that were generated into pathotype structure are groundbreaking. We have proposed an updated pathotyping system which probably will have consequences for the quarantine measure that are currently in place to control wart disease.</p> <p>Also, the knowledge that was generated for potato breeding will have an impact on society as more potato varieties with resistance to higher pathotypes will become available through the marketing chains of participating companies. Thereby a broader choice of potato variety will come available for farmers in the prevention zones.</p>
Possibly other stakeholders (spin-offs)	

Follow-up	
Did the PPP result in one or more patents (first filings)?	No
Are there any follow-up projects planned? If yes, explain. (Contract research resulting from this project, additional funding, or new PPP projects)	Yes. Based on the results from the project we could establish a new TKI project (TU-18086) entitled: "Novel tools to breed for resistance against tuber diseases caused by obligate biotrophic pathogens" Which has been granted and started in July 2019.

Deliverables/products during the entire course of the PPP (provide the titles and/or a brief description of the products/deliverables or a link to a website.)

Scientific articles:

- van de Vossenberg, B. T. L. H., Brankovics, B., Nguyen, H. D. T., van Gent-Pelzer, M. P. E., Smith, D., Dadej, K., ... van der Lee, T. A. J. (2018). The linear mitochondrial genome of the quarantine chytrid *Synchytrium endobioticum*; insights into the evolution and recent history of an obligate biotrophic plant pathogen. *BMC Evolutionary Biology*, 18, [136]. <https://doi.org/10.1186/s12862-018-1246-6>
- van de Vossenberg, B. T. L. H., Warris, S., Nguyen, H. D. T., van Gent-Pelzer, M. P. E., Joly, D. L., van de Geest, H. C., Peter J.M. Bonants, Donna S. Smith, André C. Lévesque, van der Lee, T. A. J. (2019). Comparative genomics of chytrid fungi reveal insights into the obligate biotrophic and pathogenic lifestyle of *Synchytrium endobioticum*. *Scientific Reports*, 9(1), [8672]. <https://doi.org/10.1038/s41598-019-45128-9>
- van de Vossenberg, B. T. L. H., van Gent-Pelzer, M. P. E., Boerma, M., van der Gouw, L. P., van der Lee, T. A. J., & Vossen, J. H. (2019). An Alternative Bioassay for *Synchytrium endobioticum* Demonstrates the Expression of Potato Wart Resistance in Aboveground Plant Parts. *Phytopathology*, 109(6), 1043-1052. <https://doi.org/10.1094/PHYTO-01-19-0024-R>
- Prodhomme, C., Esselink, D., Borm, T., Visser, R. G. F., Van Eck, H. J., & Vossen, J. H. (2019). Comparative Subsequence Sets Analysis (CoSSA) is a robust approach to identify haplotype specific SNPs; Mapping and pedigree analysis of a potato wart disease resistance gene *Sen3*. *Plant Methods*, 15(1), [60]. <https://doi.org/10.1186/s13007-019-0445-5>
- van de Vossenberg, B., Prodhomme, C., van Arkel, G., van Gent-Pelzer, M. P. E., Bergervoet-van Deelen, J. E. M., Brankovics, B., ... Vossen, J. H. (2019). The *Synchytrium endobioticum* *AvrSen1* triggers a Hypersensitive Response in *Sen1* potatoes while natural variants evade detection. *Molecular Plant-Microbe Interactions*, 32(11), 1536-1546. <https://doi.org/10.1094/MPMI-05-19-0138-R>

6. Prodhomme, C., Vos, P. G., Paulo, M. J., Tammes, J. E., Visser, R. G. F., Vossen, J. H., & van Eck, H. J. (2020). Distribution of P1(D1) wart disease resistance in potato germplasm and GWAS identification of haplotype-specific SNP markers. *Theoretical and Applied Genetics*. <https://doi.org/10.1007/s00122-020-03559-3>
7. Charlotte Prodhomme, Gert van Arkel, Marjan Bergervoet, Danny Esselink, Johan Rijk, Moffat Makechemu, Xizheng Chen, Michiel Schrijen, Joop Hillen, Richard G. F. Visser, Herman J. van Eck, Jack H. Vossen. Sen1 fine-mapping and candidate gene analysis. In preparation
8. Charlotte Prodhomme, Gert van Arkel, Jarosław Plich, Jasper E. Tammes, Johan Rijk, Herman J. van Eck, Richard G. F. Visser, Jack H. Vossen. A Hitchhiker's Guide to the Potato Wart Disease Resistance Galaxy. In preparation

External reports:

Oral presentation: B.T.L.H. van de Vossen, H. Nguyen, Z. Adam, L.V. Bakker, G.J. Bilodeau, P. Bonants, J.T. Chapados, J. Cullis, K. Dadej, M. Gagnon, H.C. van de Geest, M. van Gent-Pelzer, C.T. Lewis, W. McCormick, D.S. Smith, R.G.F. Visser, J.H. Vossen, S. Warris, C.A. Lévesque and T.A.J. van der Lee, Unravelling potato wart disease; a joint effort of Canadian and Dutch partners, CFIA seminar, Ottawa, Canada

Oral presentation: Jack Vossen, Westerdijk's Legacy Symposium October 30, 2017. An -omics impulse for potato wart disease resistance breeding and management.

Oral presentation: Jack Vossen, TKI netwerkdag, 18-4-2017 An -omics impulse for potato wart disease resistance breeding and management.

Oral presentation: Bart vd Vossen: The linear mitochondrial genome of the quarantine chytrid *Synchytrium endobioticum* @ EPS Get2Gether, Wageningen, 16 February 2018

Articles in professional journals/magazines:

van de Vossen, B. T. L. H. (2019). From metagenome to gene: Identification of the first *Synchytrium endobioticum* effector through comparative genomics. Wageningen: Wageningen University. <https://doi.org/10.18174/476563>

PhD thesis Charlotte Prodhomme

Title: Wart Wars: The resistant potato strikes back

Defence date: 17 April 2020

van de Vossen, B. T. L. H., van der Lee, T. A. J., & Nguyen, H. D. T. (2019). The 2019 Potato Wart Disease workshop: shared needs and future research directions. *EPPO Bulletin*. <https://doi.org/10.1111/epp.12638>

(Poster) presentations at workshops, seminars or symposia.

Poster presentation: An integrated genomics and effectoromics approach for potato wart disease resistance breeding. Prodhomme C.P.M., Vos P.G., Visser R.G.F., van Eck H.J., Vossen J. H. EUCARPIA Section Potatoes, 18th Joint Meeting. Vico Equense, Italy - November 15th - 18th, 2015.

Poster presentations: Unravelling potato wart disease; determination of the draft genome of the obligate biotrophic fungus *Synchytrium endobioticum*, B.T.L.H. van de Vossen, M. van Gent-Pelzer, E.G.W.M. Schijlen, S. Warris, H.C. van de Geest, P. Bonants, C.A. Lévesque, J. Cullis, C.T. Lewis, J.T. Chapados, W. McCormick, K. Dadej, Z. Adam, G.J. Bilodeau, M. Gagnon, D.S. Smith, R.F.G. Visser, J.H. Vossen, T.A.J. van der Lee, COST action Sustain Workshop: Evolutionary Genomics of plant pathogens 26 - 28 August 2015, Christian-Albrechts University of Kiel, Kiel, Germany

Poster presentation: B.T.L.H. van de Vossen, M. van Gent-Pelzer, E.G.W.M. Schijlen, S. Warris, H.C. van de Geest, P. Bonants, C.A. Lévesque, J. Cullis, C.T. Lewis, J.T. Chapados, W. McCormick, K. Dadej, Z. Adam, G.J. Bilodeau, M. Gagnon, D.S. Smith, R.F.G. Visser, J.H. Vossen, T.A.J. van der Lee, Unravelling potato wart disease; determination of the draft genome of the

obligate biotrophic fungus *Synchytrium endobioticum*, EEC-EPPO Workshop on Euphresco, 26-29-7-2016, Moscow, Russia

Poster presentation: An integrated genomics and effectoromics approach for potato wart disease resistance breeding. Prodhomme C.P.M., Vos P.G., Visser R.G.F., van Eck H.J., Vossen J. H. EUCARPIA Section Potatoes, 18th Joint Meeting. Vico Equense, Italy – November 15th – 18th, 2015.

Poster presentation: Unravelling potato wart disease; determination of the draft genome of the obligate biotrophic fungus *Synchytrium endobioticum*, B.T.L.H. van de Vossen, M. van Gent-Pelzer, E.G.W.M. Schijlen, S. Warris, H.C. van de Geest, P. Bonants, C.A. Lévesque, J. Cullis, C.T. Lewis, J.T. Chapados, W. McCormick, K. Dadej, Z. Adam, G.J. Bilodeau, M. Gagnon, D.S. Smith, R.F.G. Visser, J.H. Vossen, T.A.J. van der Lee, COST action Sustain Workshop: Evolutionary Genomics of plant pathogens 26 - 28 August 2015, Christian-Albrechts University of Kiel, Kiel, Germany

Poster presentation: Bart van de Vossen: "The linear mitochondrial genome of the quarantine pest *Synchytrium endobioticum*; insights in the evolutionary history of an obligate biotroph"
Poster: 1233-P @ICPP meeting Boston, August 2018

Poster presentation: Charlotte Prodhomme: "Bulk Segregant K-mer Analysis (BSKA): a novel and versatile tool for genetic research" @Sol2018, The 15th Solanaceae Conference. Chiang Mai, Thailand. 30.09 – 04.10 2018:

Oral presentation: Bart vd Vossen: The linear mitochondrial genome of the quarantine chytrid *Synchytrium endobioticum*, EPS meeting Lunteren, 10 April 2018

Oral presentation: Jack Vossen: AvrSen1 is the first effector from a chytrid pathogen. @ 9th Joint Meeting of the EAPR Section 'Breeding & Varietal Assessment' and EUCARPIA Section Potatoes, Rostock-Warnemuende Germany. 03-06.12.2018

Poster presentation: Charlotte Prodhomme: "Bulk Segregant K-mer Analysis (BSKA): a novel and versatile tool for genetic research" @Sol2018, The 15th Solanaceae Conference. Chiang Mai, Thailand. 30.09 – 04.10 2018:

Oral presentation: Charlotte Prodhomme: "Bulk Segregant K-mer Analysis (BSKA) Facilitates Mapping a Potato Wart Disease Resistance Gene and Identifies Haplotype Specific SNPs@ 9th Joint Meeting of the EAPR Section 'Breeding & Varietal Assessment' and EUCARPIA Section Potatoes, Rostock-Warnemuende Germany. 03-06.12.2018

Oral presentation: Marga van Gent-Pelzer. Potato wart disease in the Netherlands: a historic perspective from a molecular view. Potato wart disease workshop. June 2019, Wageningen.

Oral presentation: Bart van de Vossen. The linear mitochondrial genome of the quarantine pest *Synchytrium endobioticum*; insights in the evolutionary history of an obligate biotroph. Potato wart disease workshop. June 2019, Wageningen.

Oral presentation: Bart van de Vossen: Identification of the AvrSen1 gene: towards molecular pathotyping. Potato wart disease workshop. June 2019, Wageningen.

Oral presentation: Charlotte Prodhomme. Stacking of resistance loci to give full resistance to higher pathotypes of *S. endobioticum*. Potato wart disease workshop. June 2019, Wageningen.

TV/ radio / social media / newspaper:

A symposium was coorganised by WUR participants of this project and the Dutch NPPO from June 26th till 28th. All stakeholders in the potato wart resistance field were represented ranging from farmers organisations, to potato breeders, to scientists, to NPPOs from all over the world, to governmental organisations.

<https://english.nvwa.nl/topics/national-plant-protection-organization-nppo/potato-wart-disease-workshop>

Remaining deliverables (techniques, devices, methods, etc.):

Data sharing:

- Phenotypic data and molecular markers have been shared with the consortium members using a password protected teamsite
- genomic data have been uploaded as described in publication 2

Methods:

- Novel phenotyping methods have been produced as described in publications 3 and 5
- Markers for breeding have been described in publications 4, 6 and 7